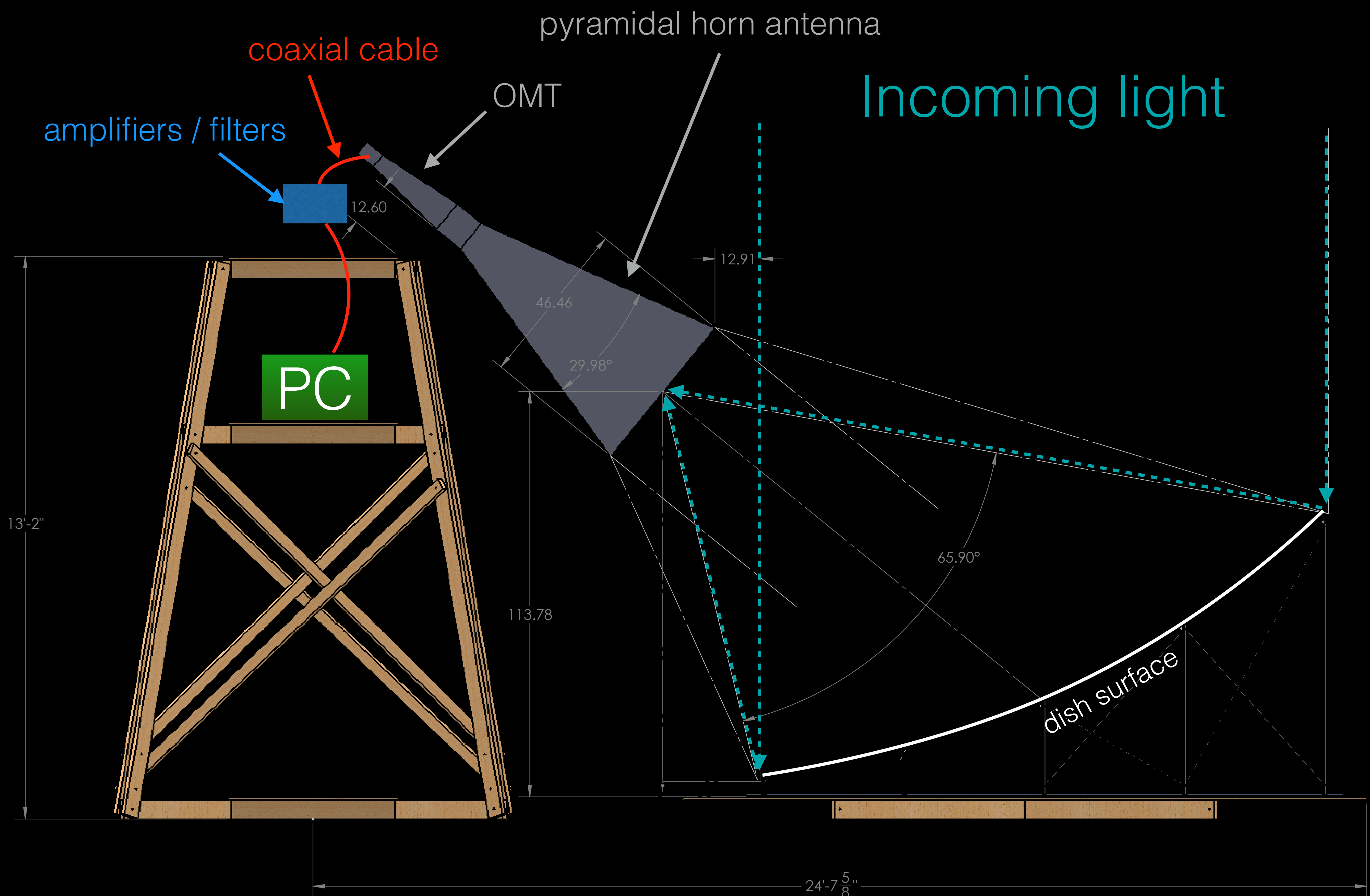
BMX Antenna

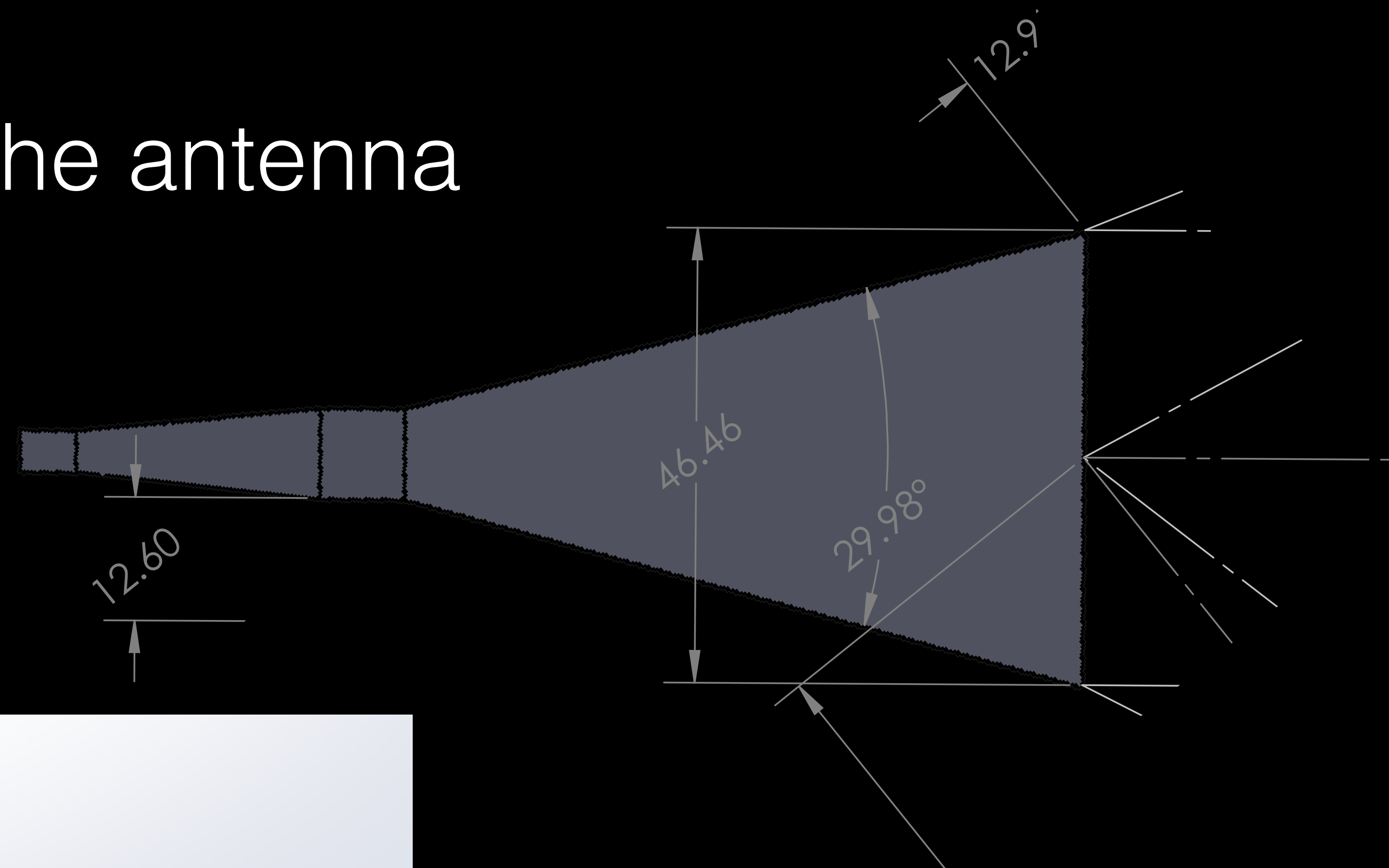
Chris Sheehy

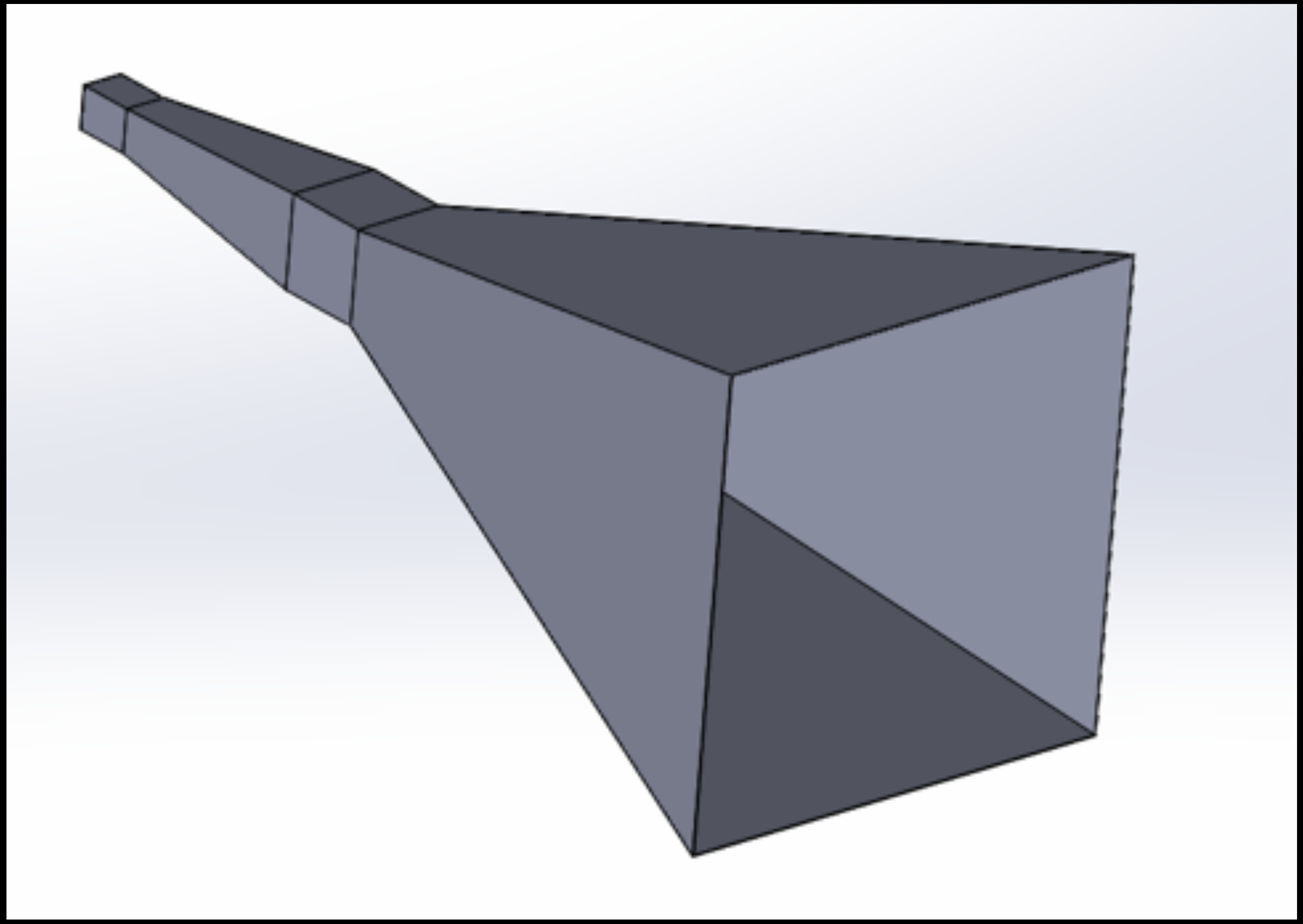
Dec 13, 2016



pyramidal horn antenna
coaxial cable
OMT
Incoming light
amplifiers / filters
12.60
12.91
46.46
29.98°
PC
13'-2"
65.90°
113.78
dish surface
24'-7 5/8"

This talk will focus on the antenna

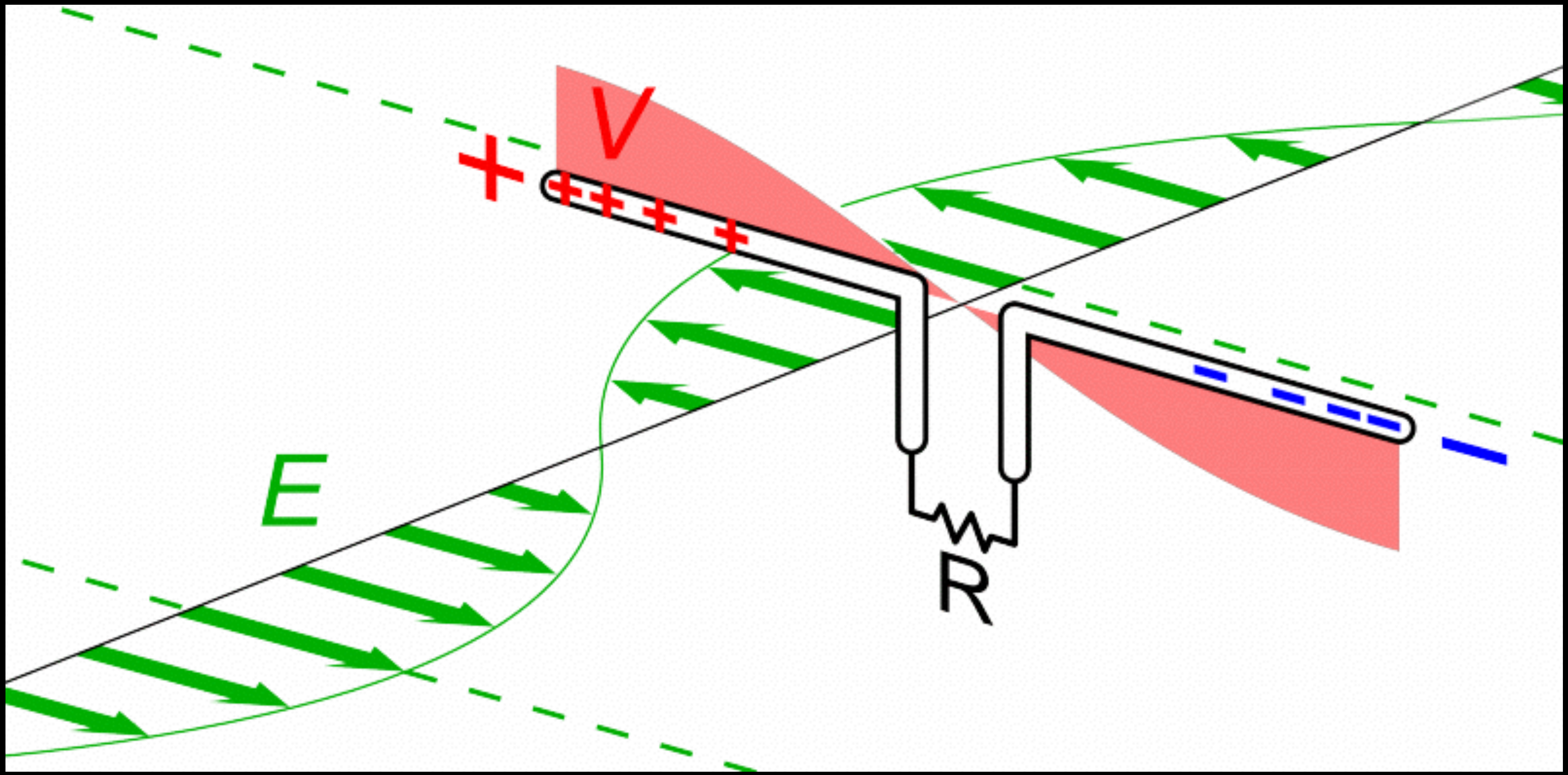




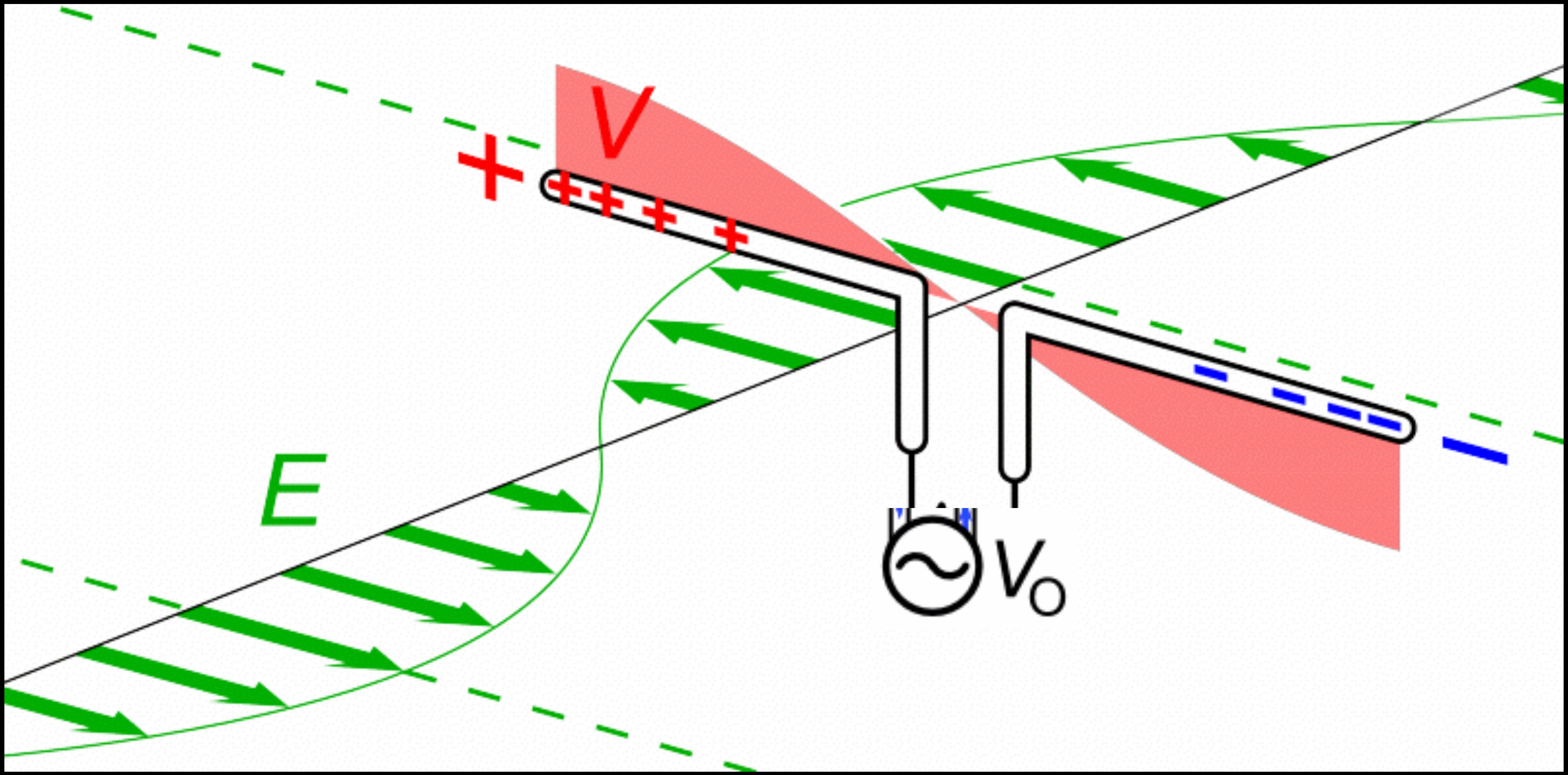
- From Kraus' *Antennas:* "An antenna is a transition device, or transducer, between a guided wave and a free-space wave, or vice versa."

- As in all antenna design, the name of the game is converting electric field oscillations in free space into current in a wire with as high efficiency as possible.

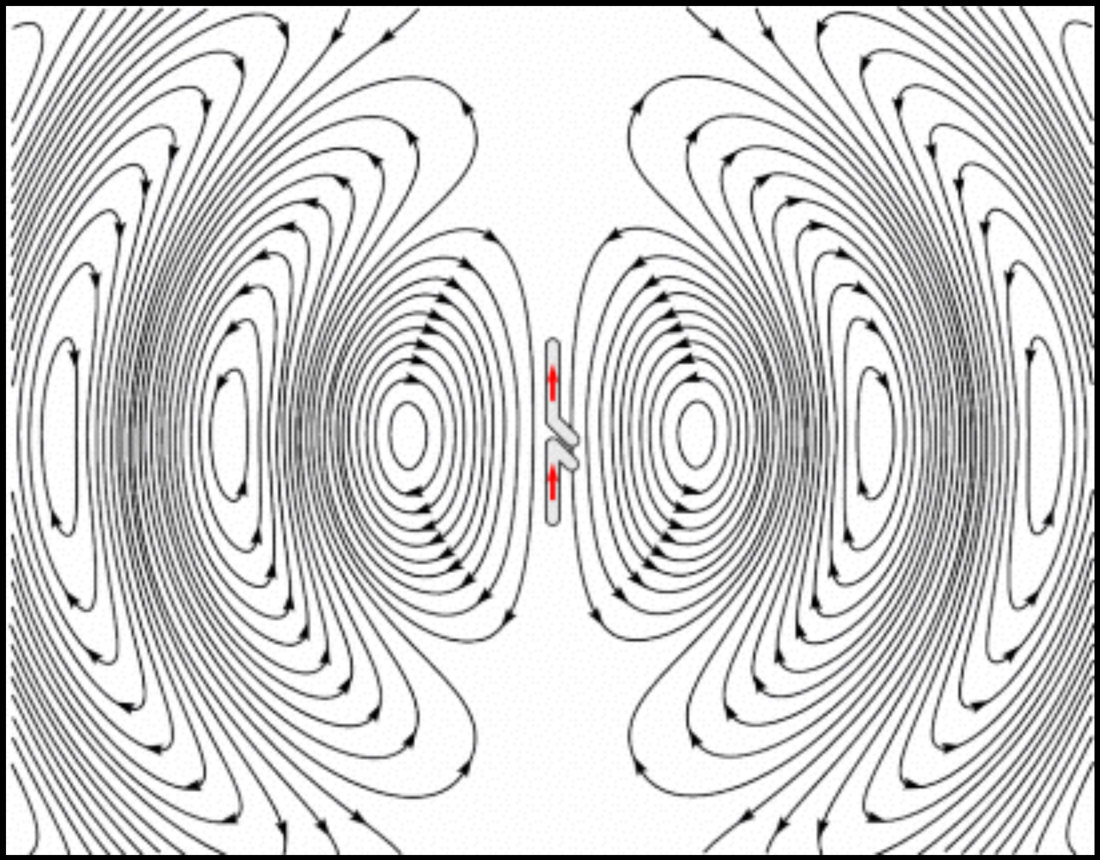
Simplest antenna is really just a bare wire, i.e. a dipole antenna



Alternately, drive with an AC voltage source and you generate EM waves



Receiving vs. transmitting is completely symmetric. The power emitted in EM waves as a function of angle is called the antenna's "beam." By symmetry it is the same as the current induced by an EM wave as a function of its angle of incidence.



- A dipole has a torus beam, limited frequency response, and is sensitive to only one polarization. In general, want a tightly focused beam, wide bandwidth, and dual polarization.

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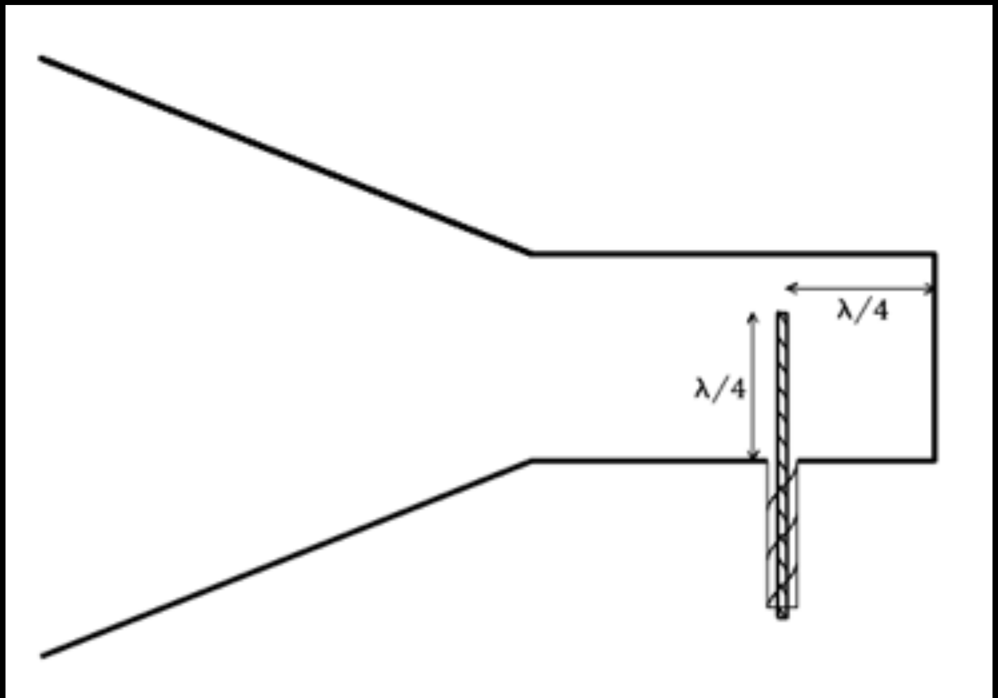
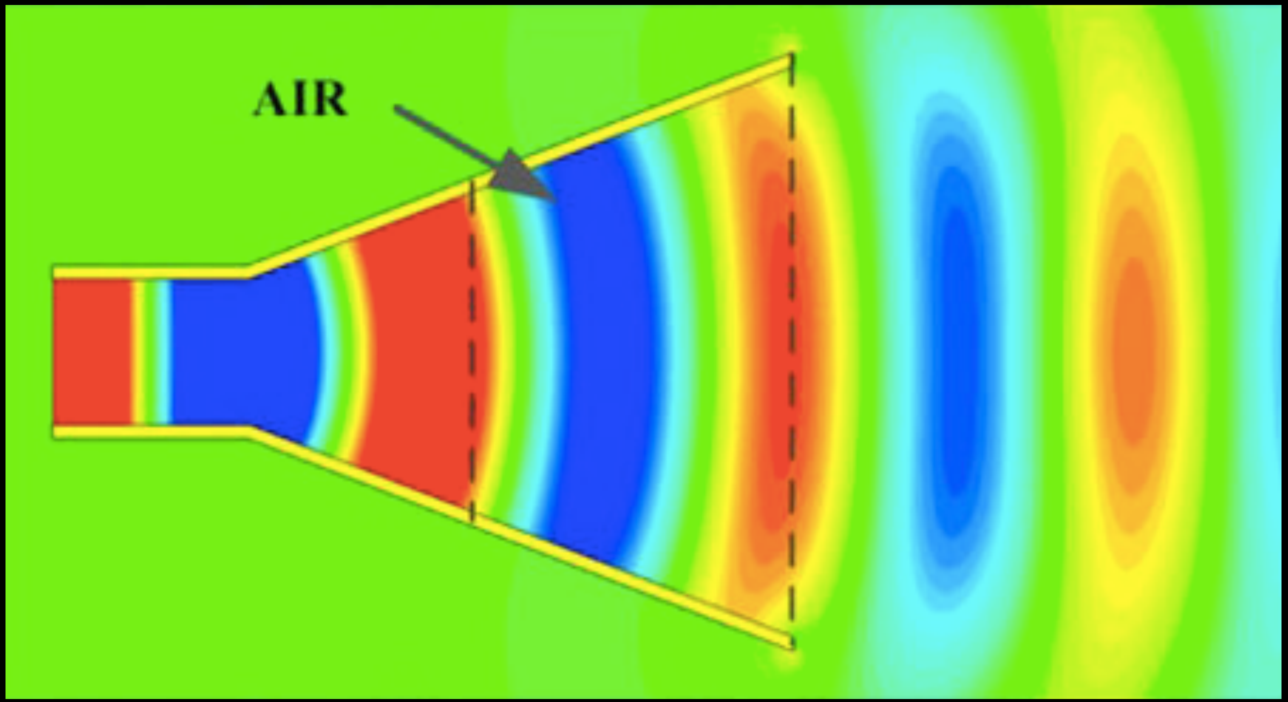
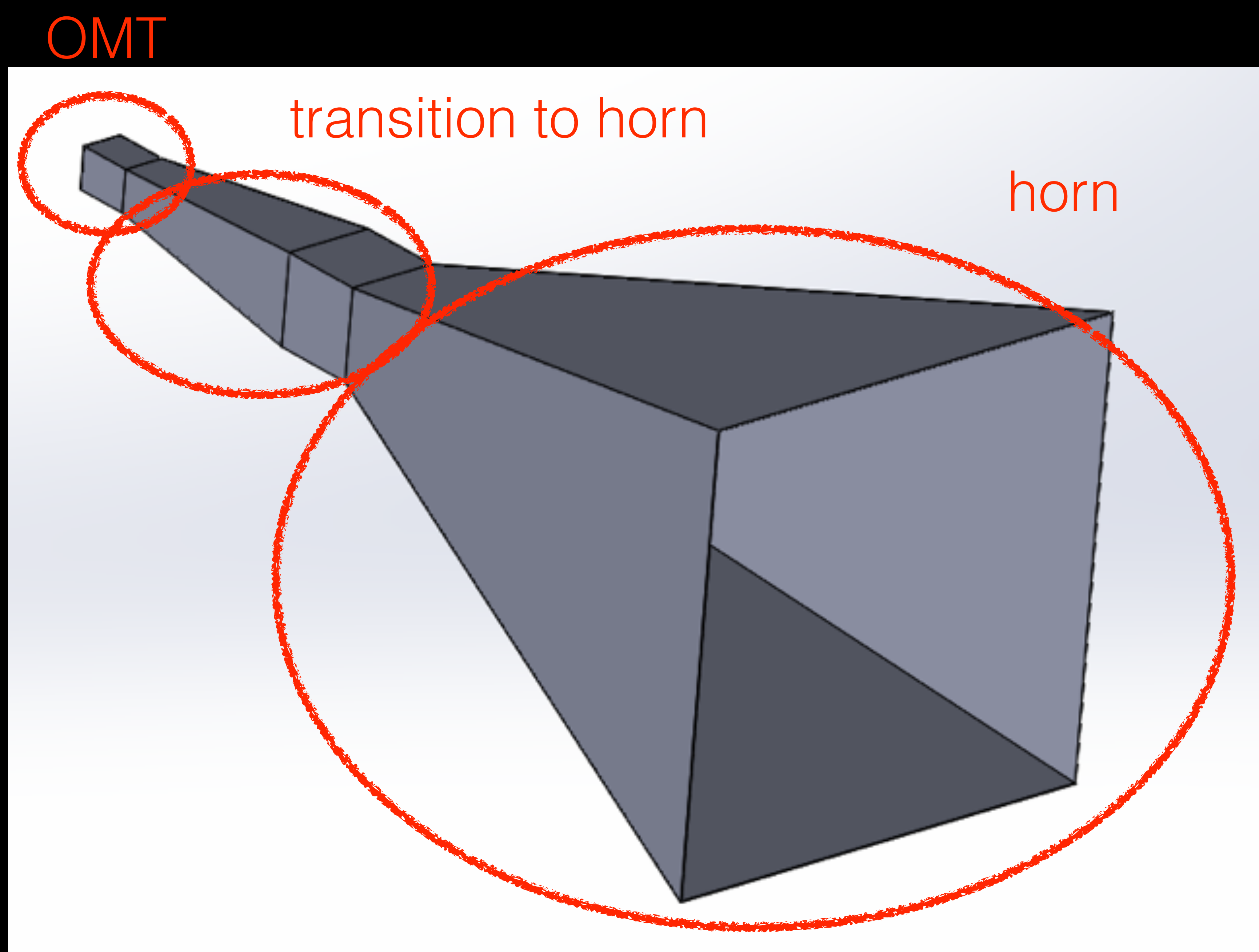
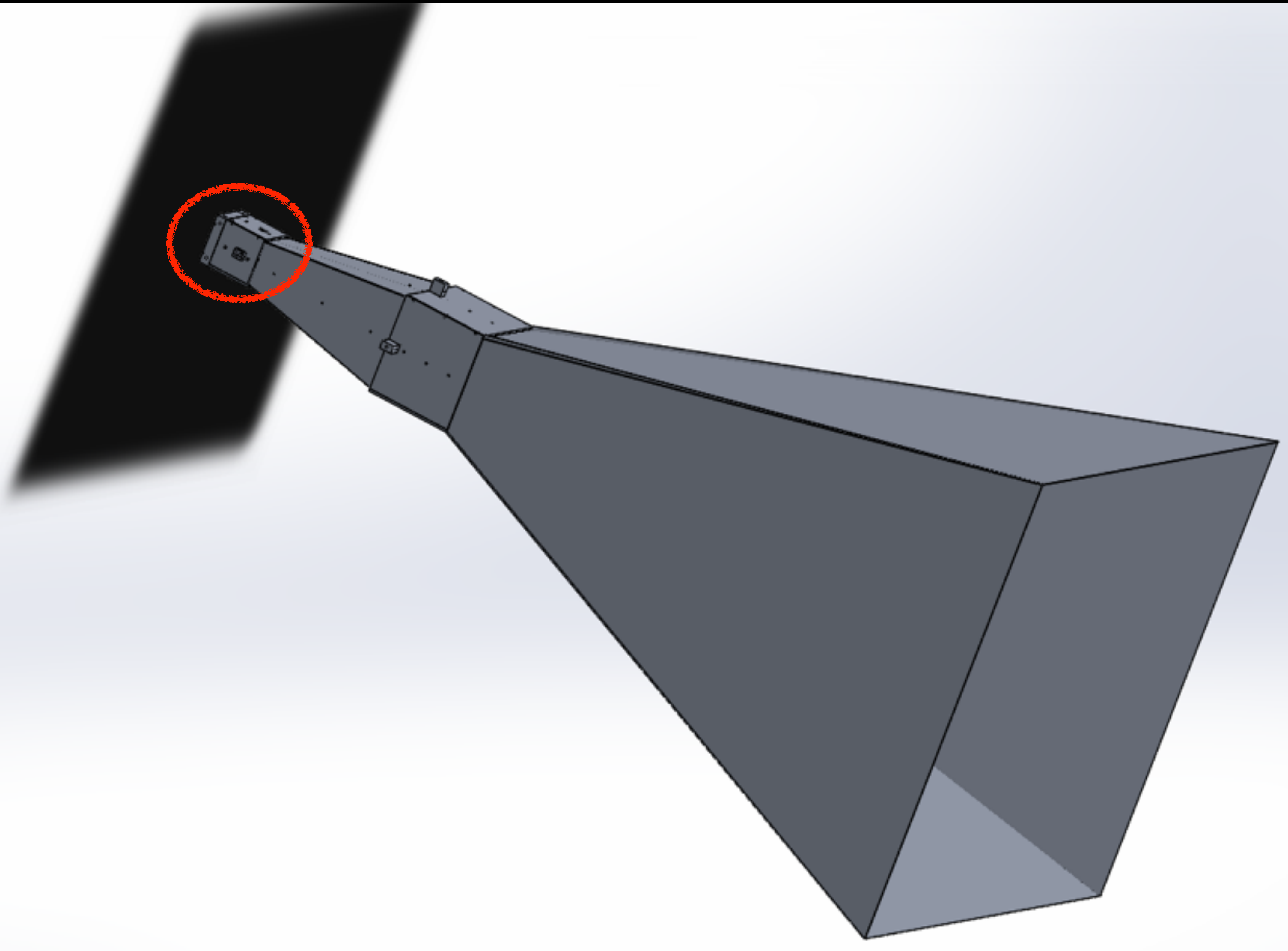
- Solution: add a “feed horn” to define beam and play tricks with waveguides to couple to coax and keep bandwidth high



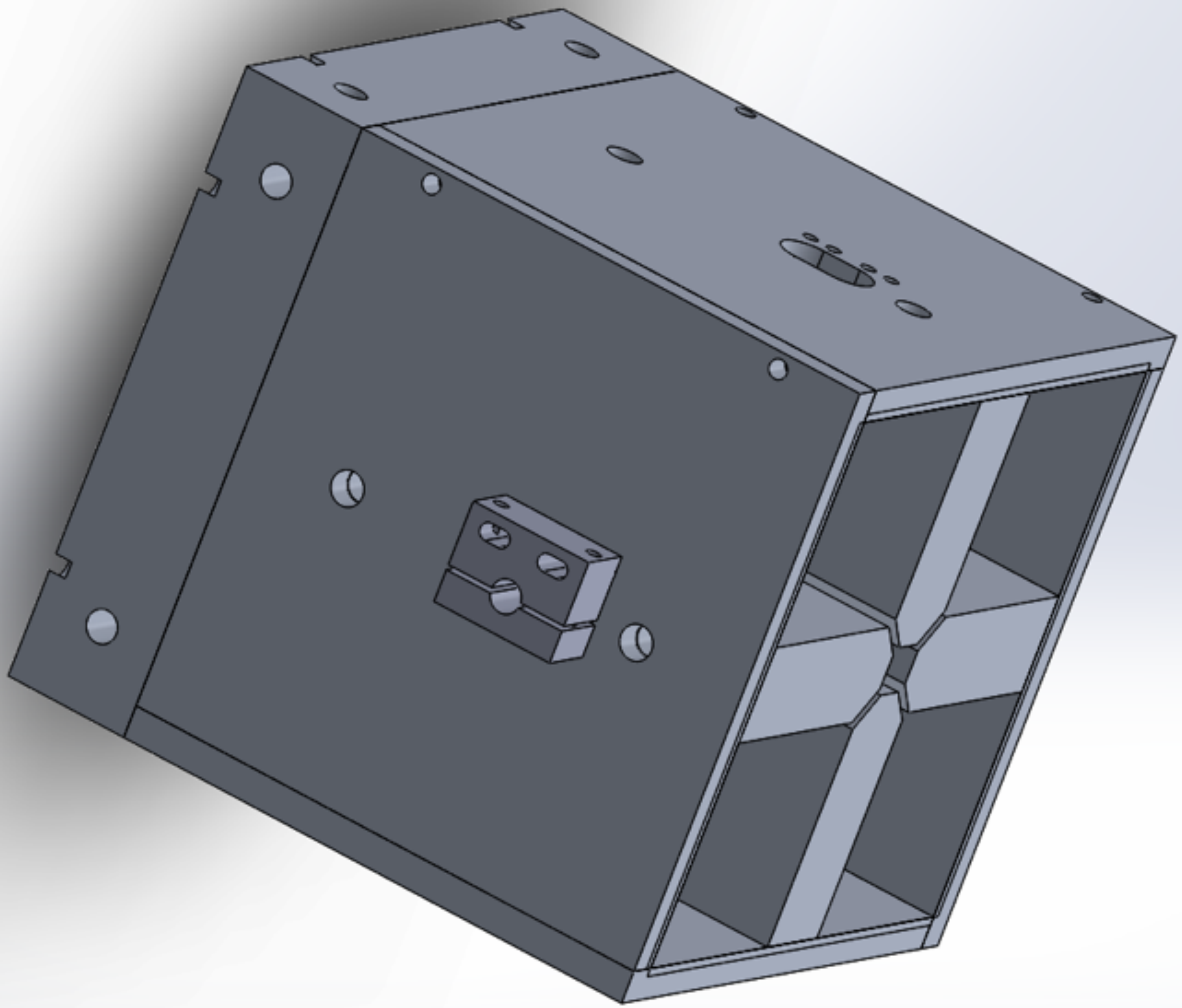


Optionally, one can also add an “orthomode transducer” (OMT) to split polarization into two.


OMT
transition to horn
horn



“quad ridge” OMT



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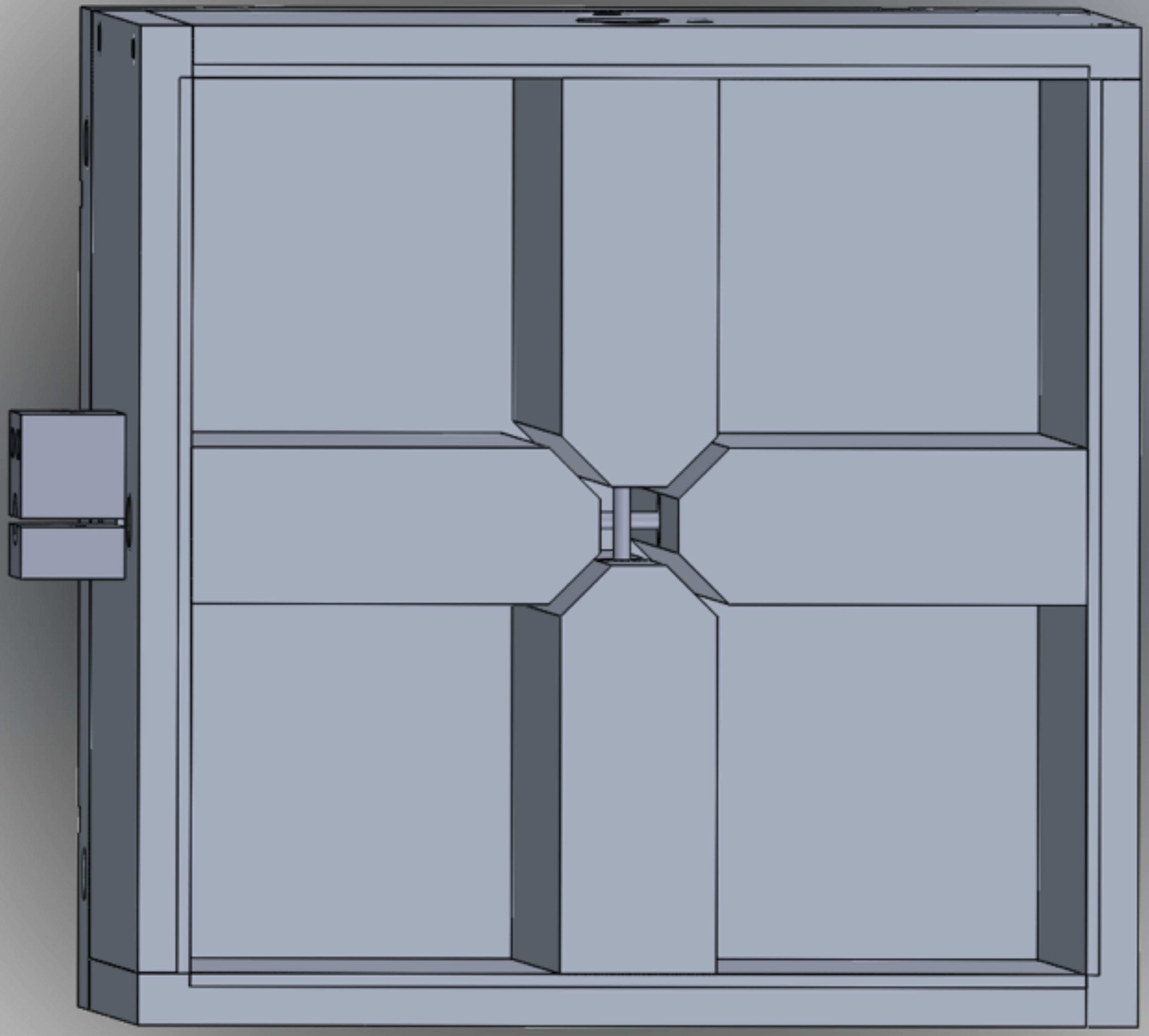
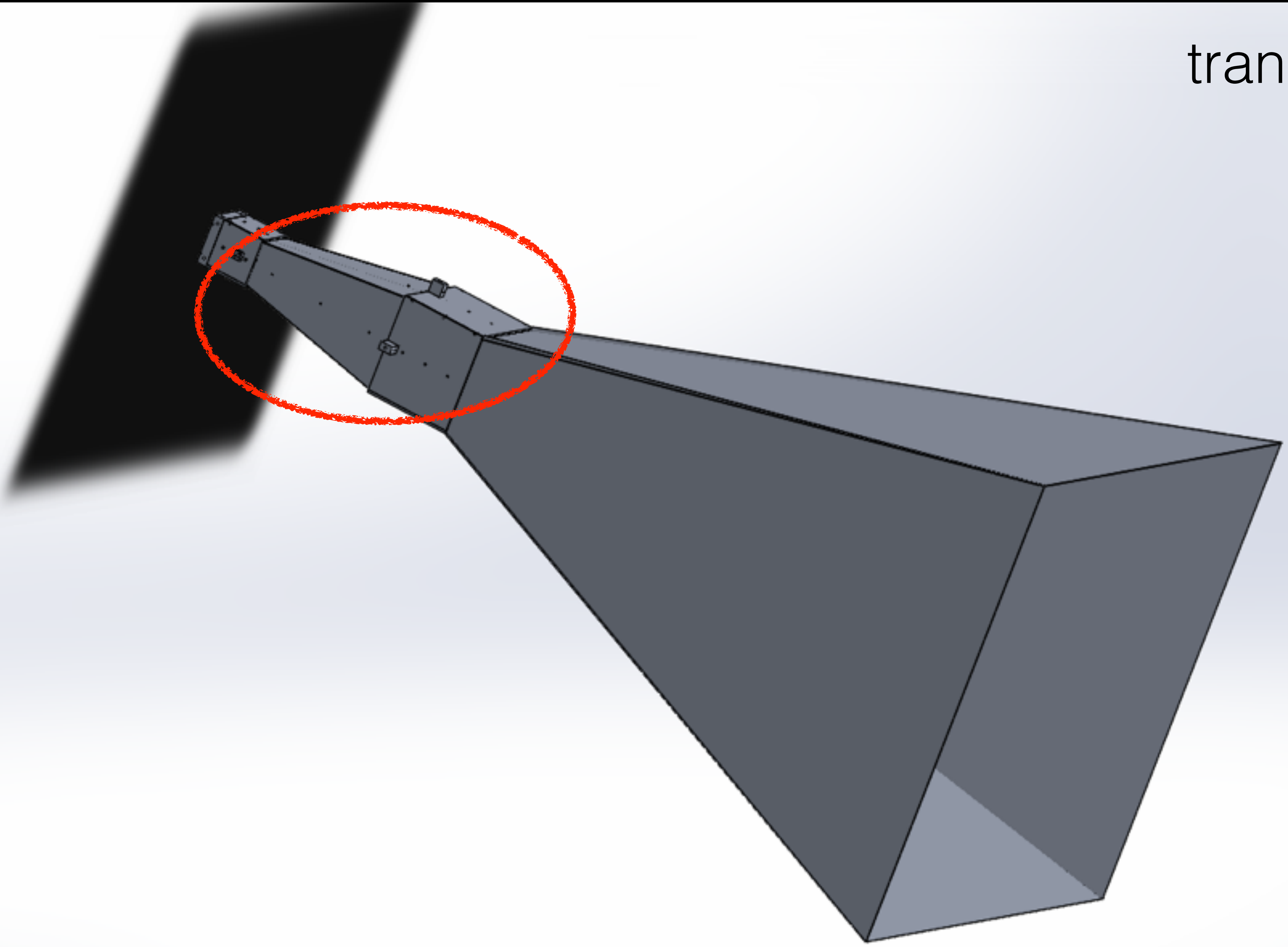
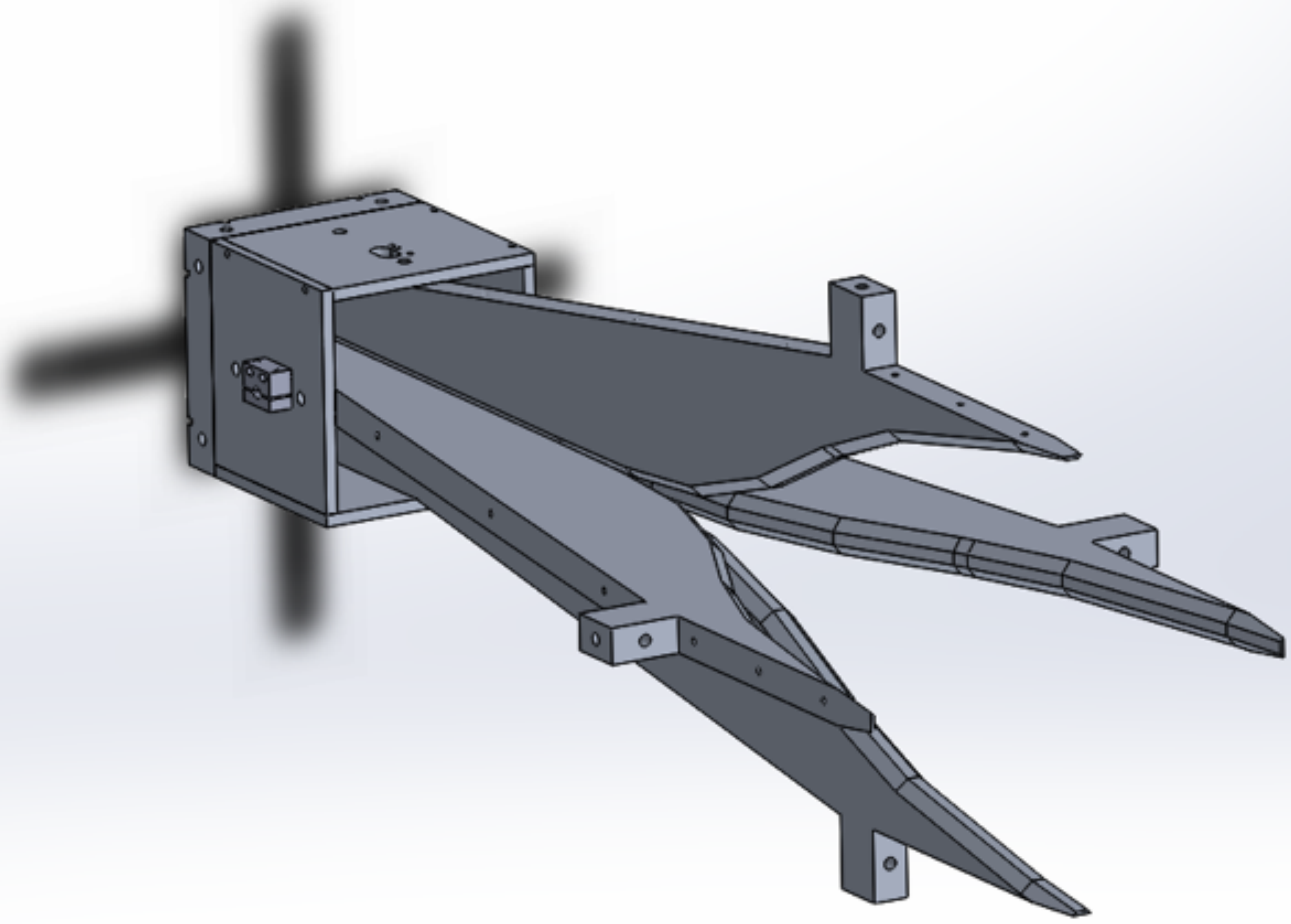


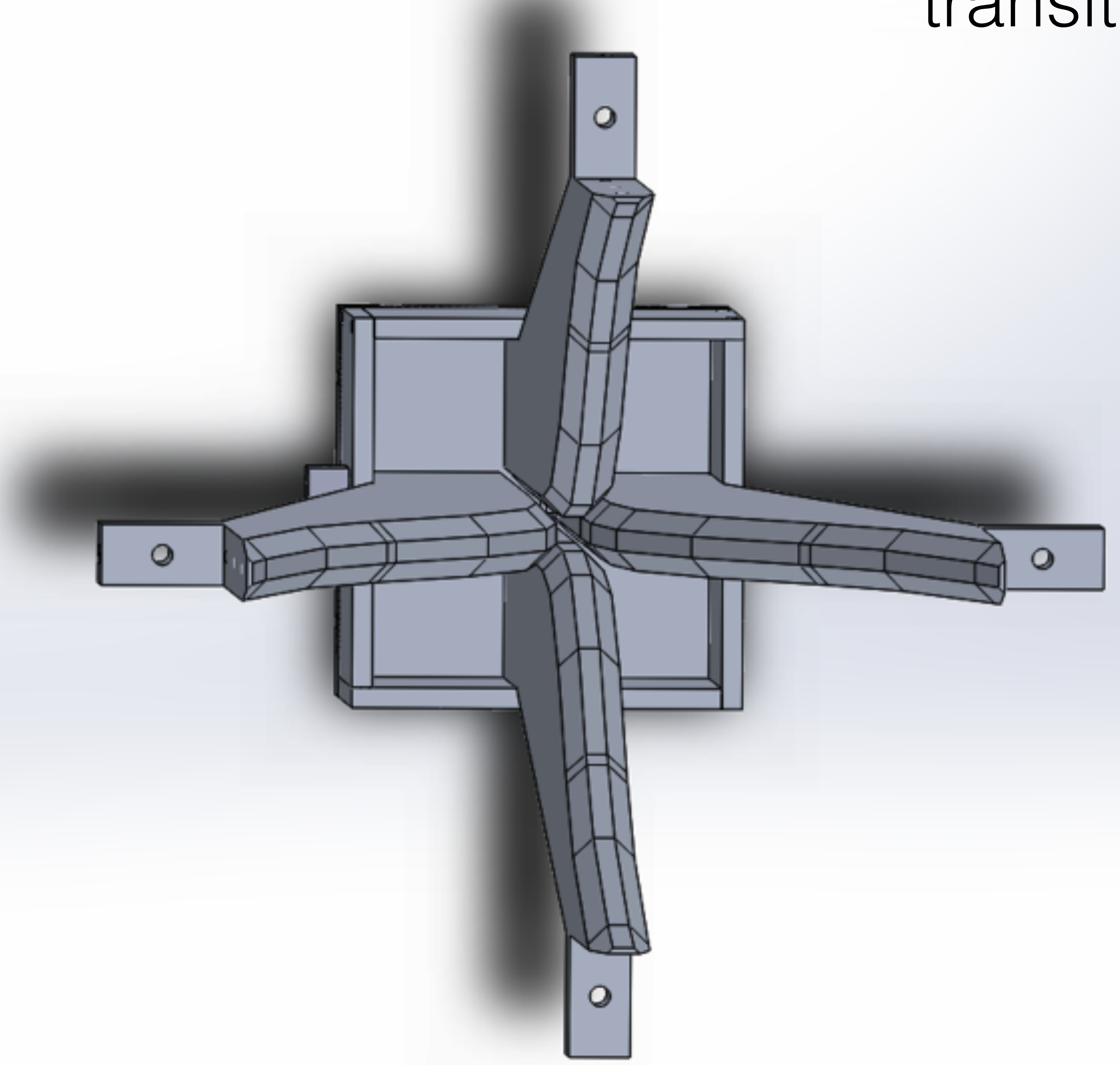
transition



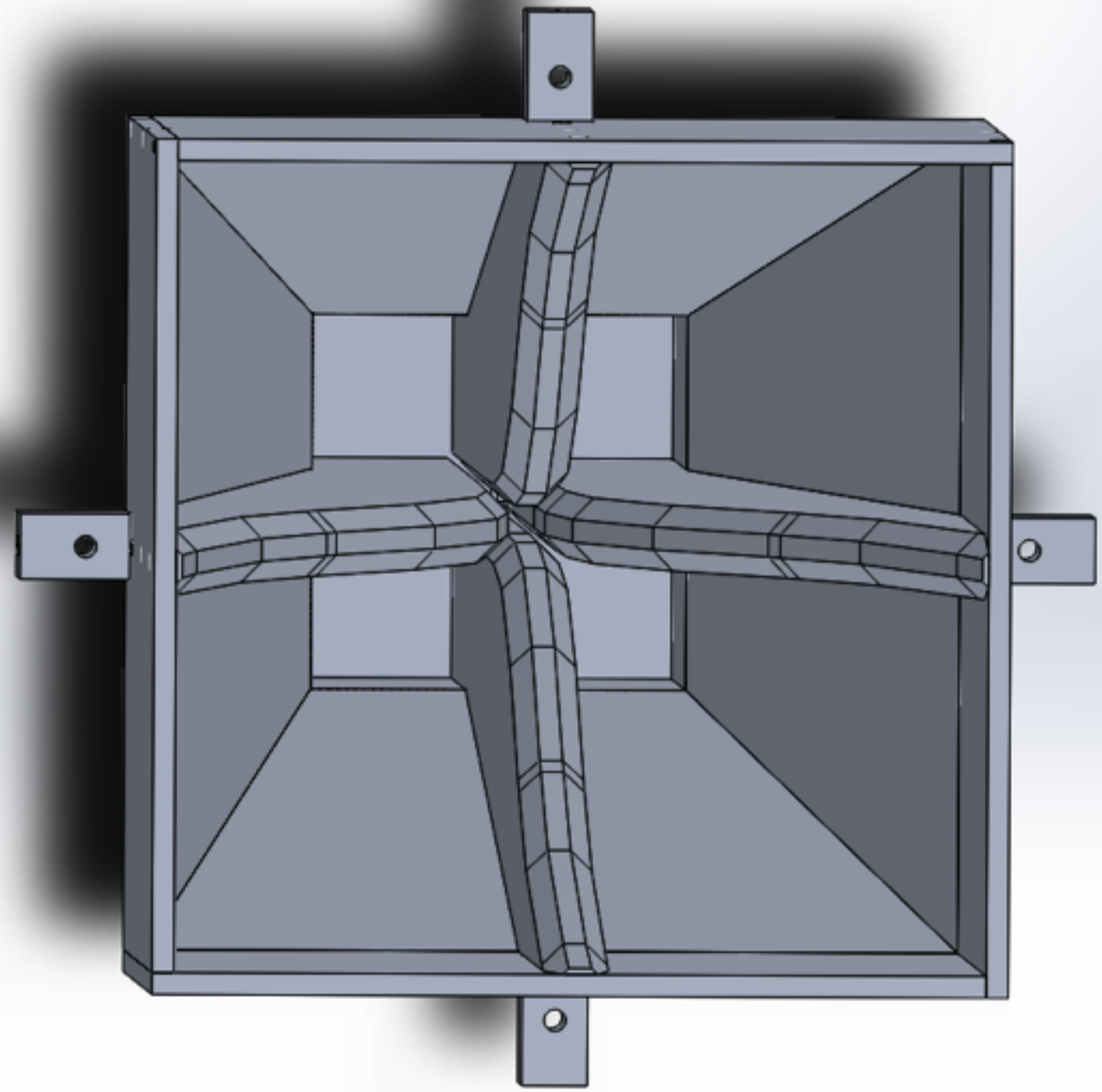
transition



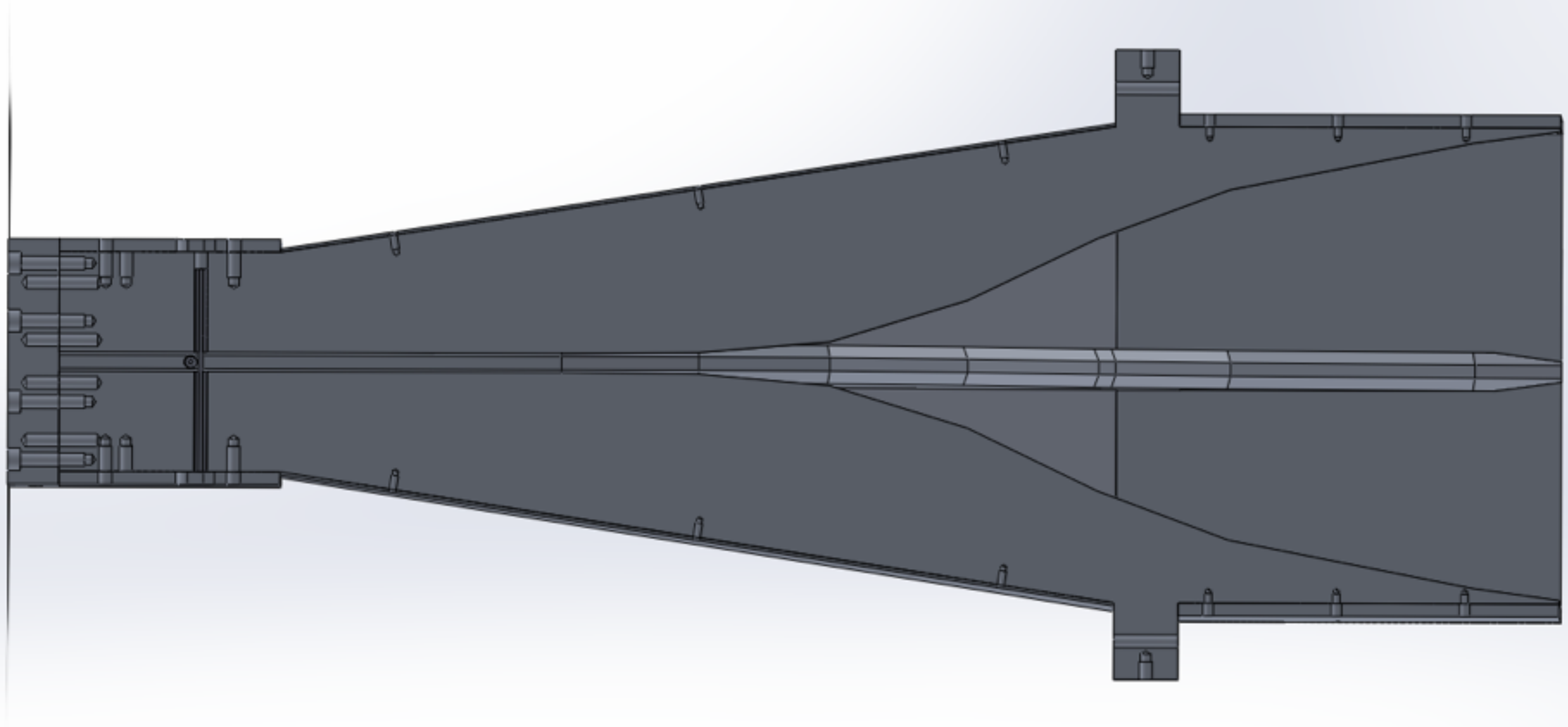
transition



transition



OMT + transition (cross section)



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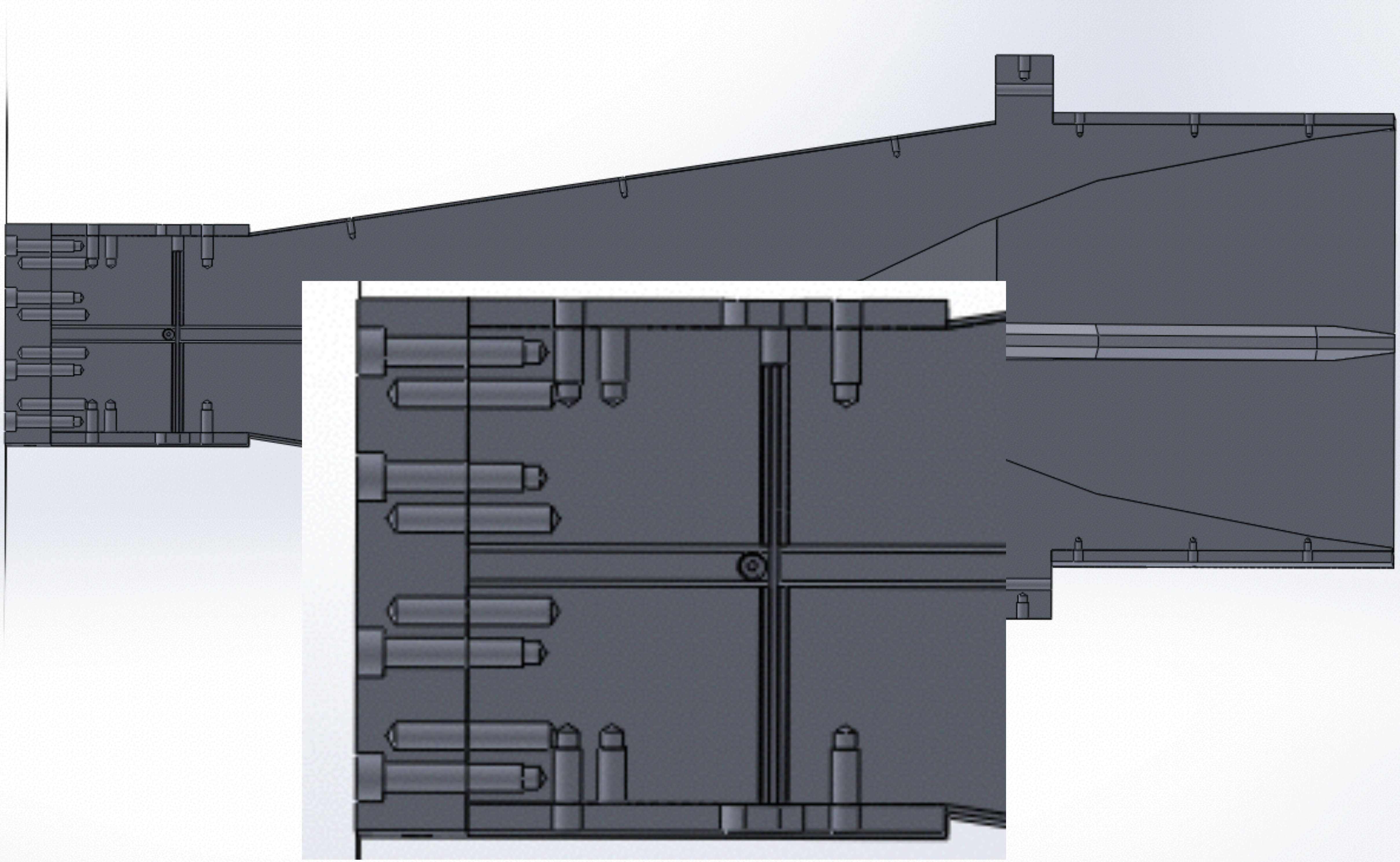
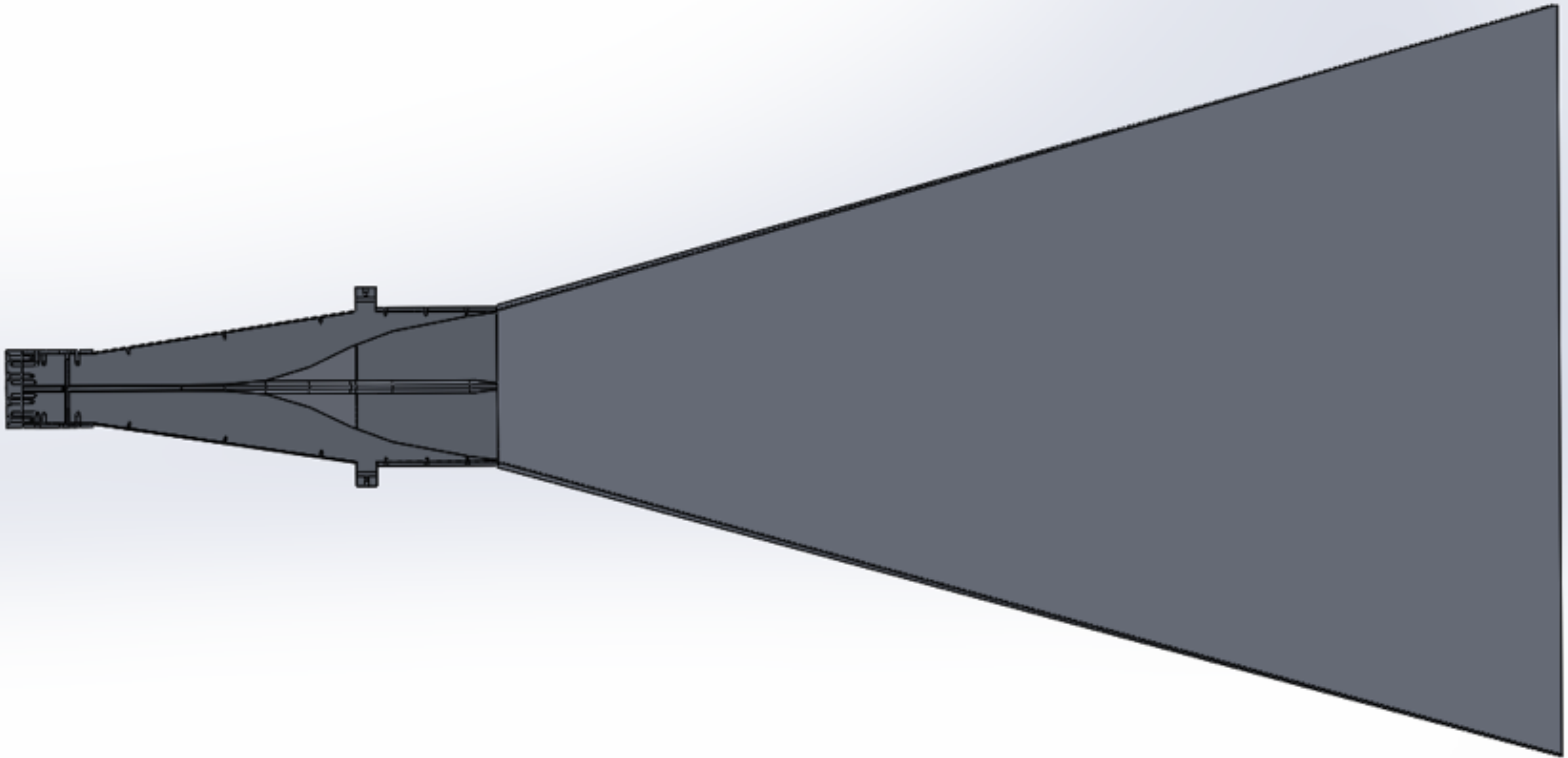
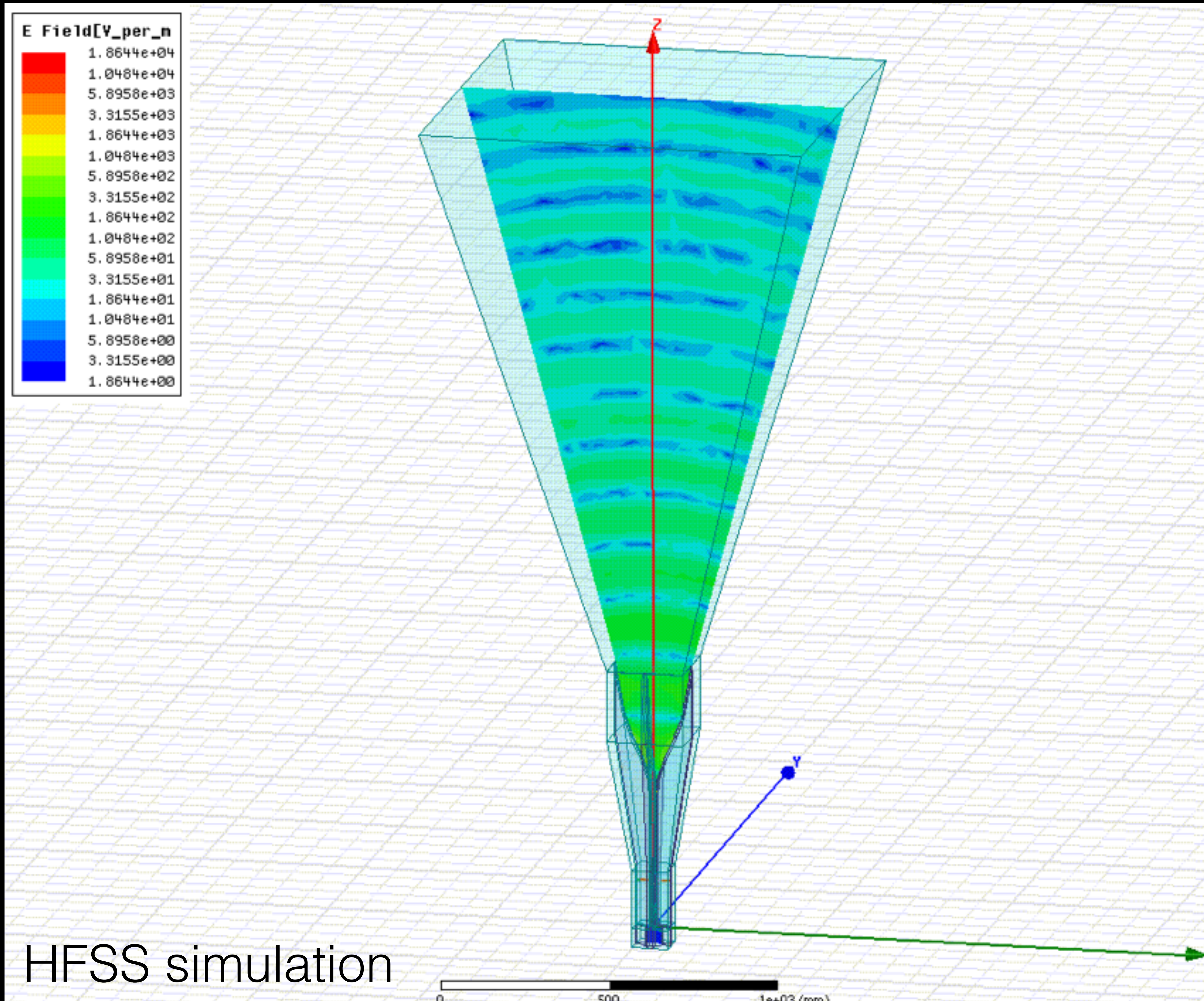
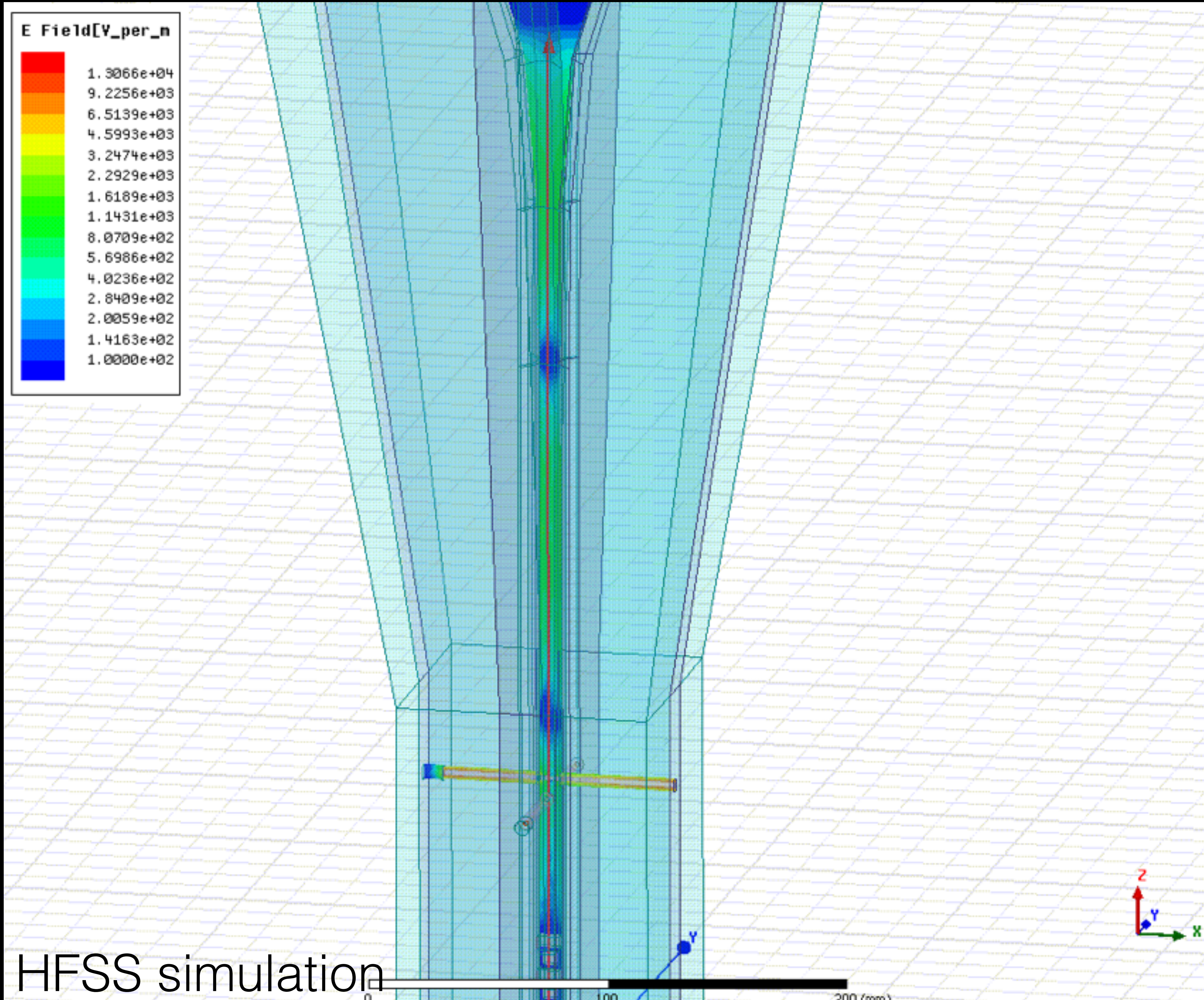


OMT + transition + feed horn (cross section)




E Field[V_per_m
1.8644e+04
1.0484e+04
5.8958e+03
3.3155e+03
1.8644e+03
1.0484e+03
5.8958e+02
3.3155e+02
1.8644e+02
1.0484e+02
5.8958e+01
3.3155e+01
1.8644e+01
1.0484e+01
5.8958e+00
3.3155e+00
1.8644e+00
Z
Y
X
0
500
1e+03 (mm)
HFSS simulation



HFSS simulation

- Parametrize the transmission and reflection of a network by the “scattering matrix” S.

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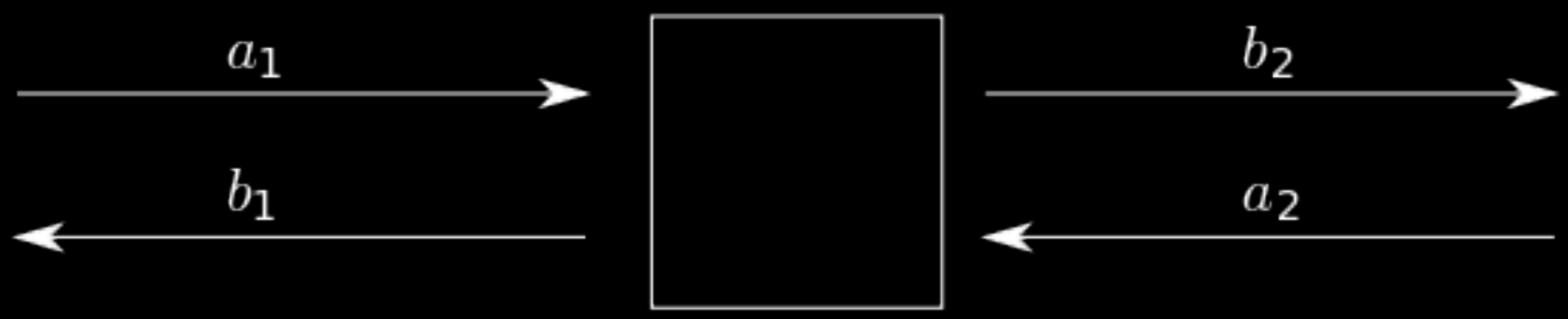

(a and b typically have units of power)

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$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

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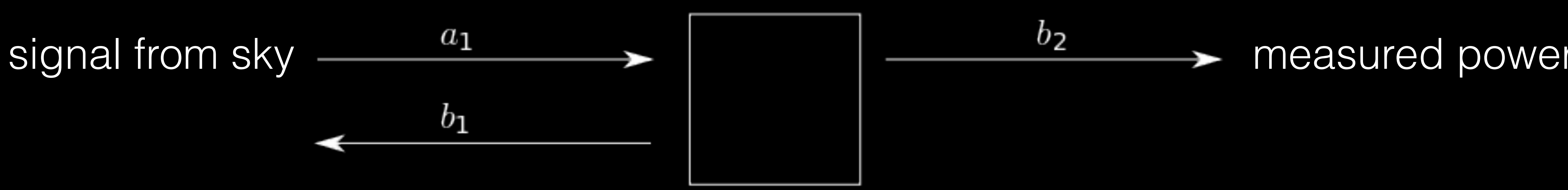
  - $b_2 = S_{21} * a_1$ (S_{21} is the throughput)
  - $b_1 = S_{11} * a_1$ (S_{11} is the reflection)
  - In a lossless system, $S_{11} + S_{21} = 0$



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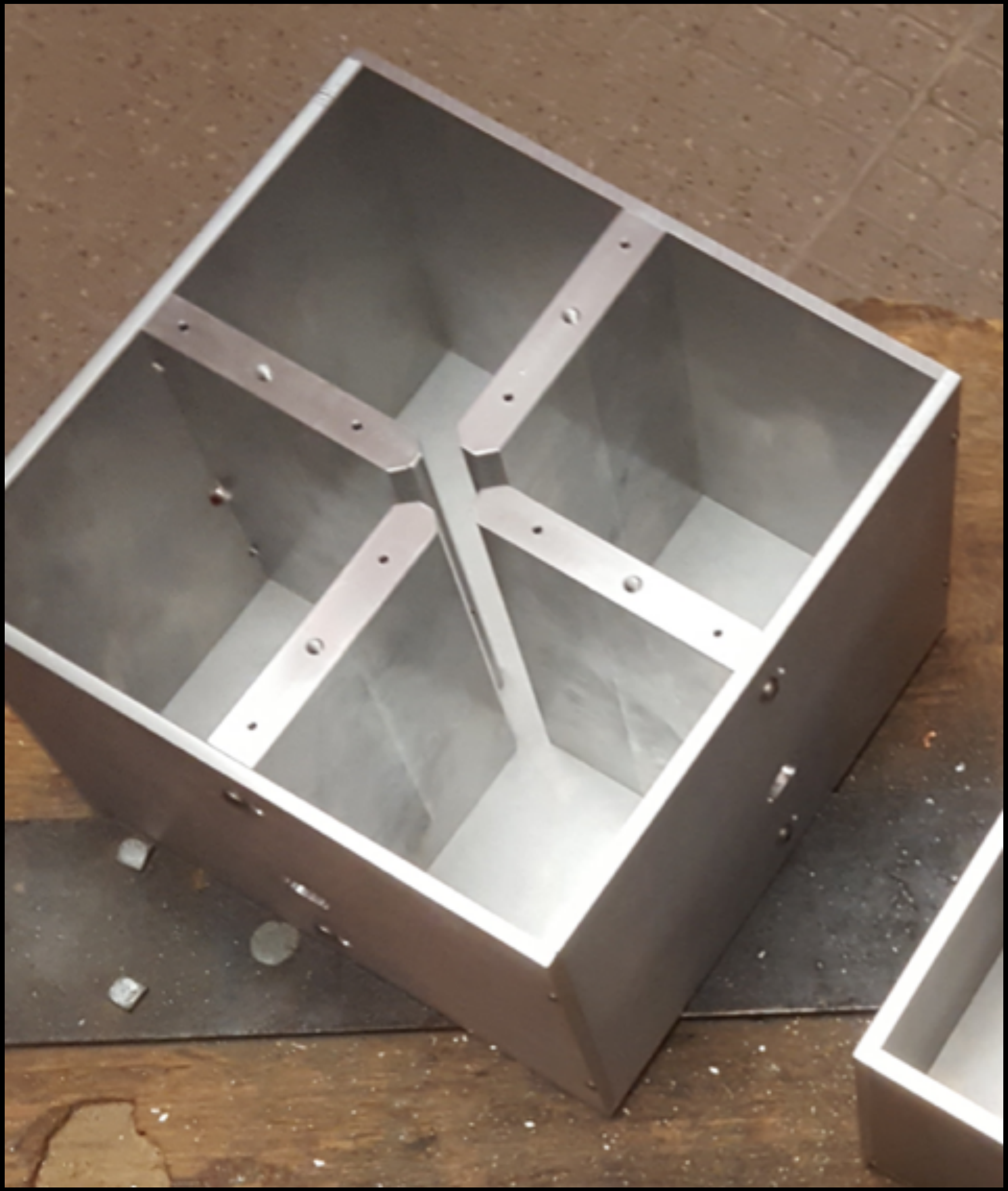
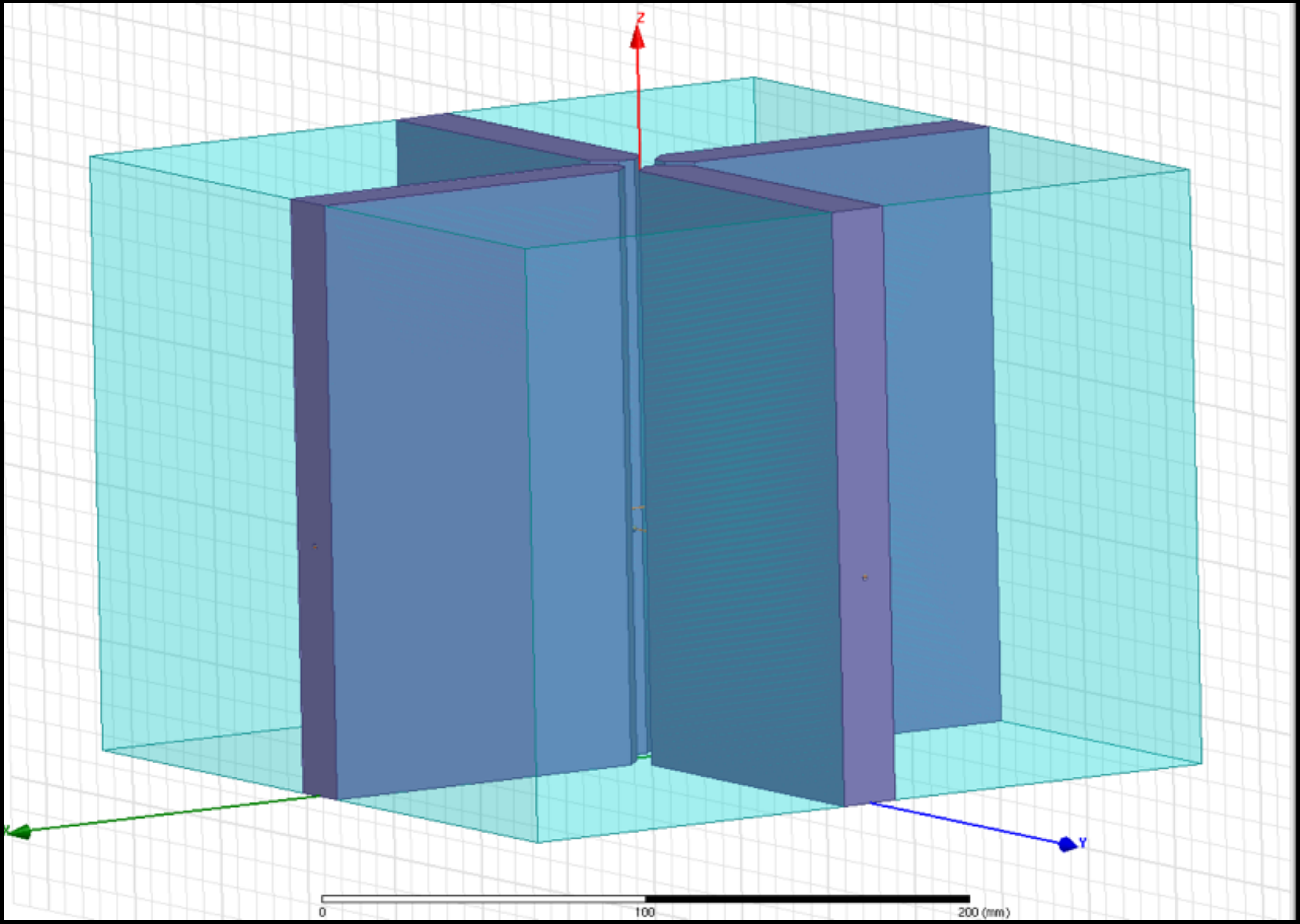
- For passive devices like filters, $0<S_{21}<1$. For an amplifier, $S_{21}>1$.

We want to design a device that has S_{21}~1 and S_{11}~0.
(Maximize throughput, minimize reflections.)

OMT first iteration from Jeff McMahon and Remington (with transition yet to be designed)



HFSS model



XY Plot 1
HFSSDesign1
Curve Info
0 dB
-0.6 dB
-4 dB
S21 (dB)
0.6 GHz
1.5 GHz
Freq [GHz]
0.40
0.80
1.00
1.20
1.40
-1.00
-2.00
-5.00

“dB” is ubiquitous in the RF engineering world.

Quotes a ratio of measured power (units Watts) to a reference power:

$$10\log_{10}\left(\frac{P}{P_0}\right)\,\mathrm{dB}$$

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$$10\log_{10}\left(S_{\mathrm{ij}}\right)\,\mathrm{dB}$$

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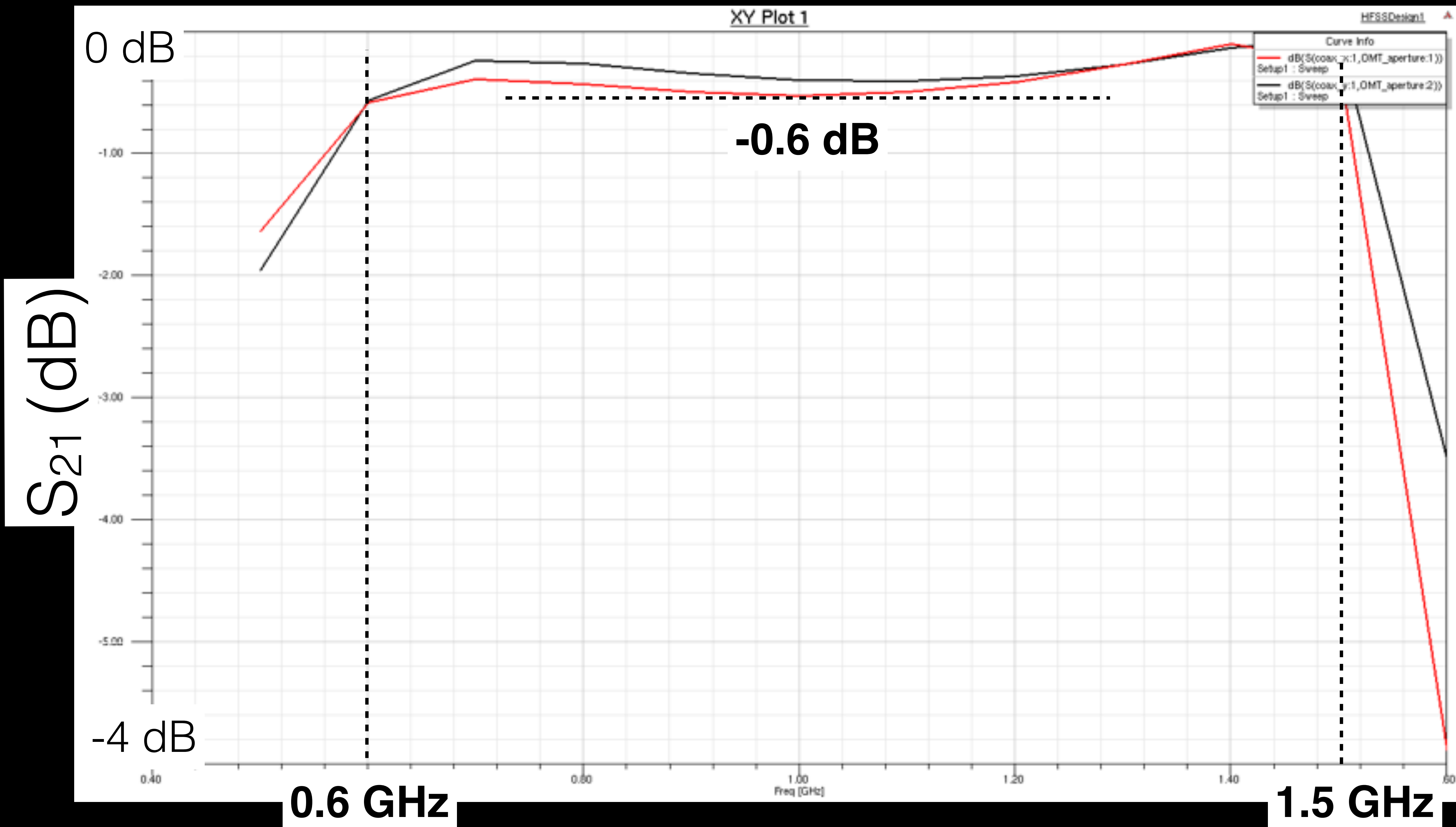
$$10\log_{10}\left(S_{ij}\right)\ \mathrm{dB}$$

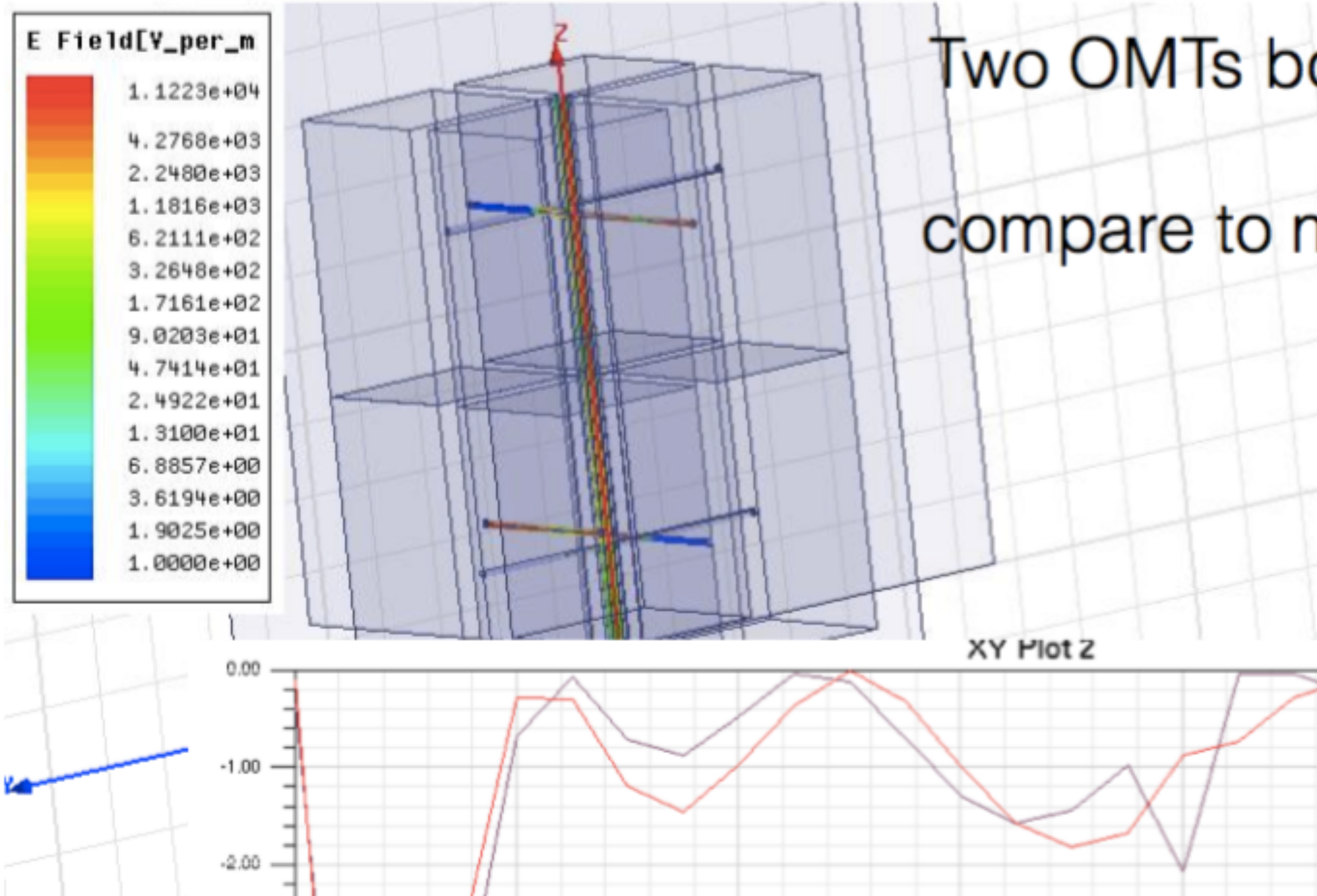
-20 dB -> 0.01
-10 dB -> 0.1
-3 dB -> 0.5
-1 dB -> 0.79
-0.5 dB -> 0.89
0 dB -> 1
+3 dB -> 2
+10 dB -> 10
+100 dB -> 100

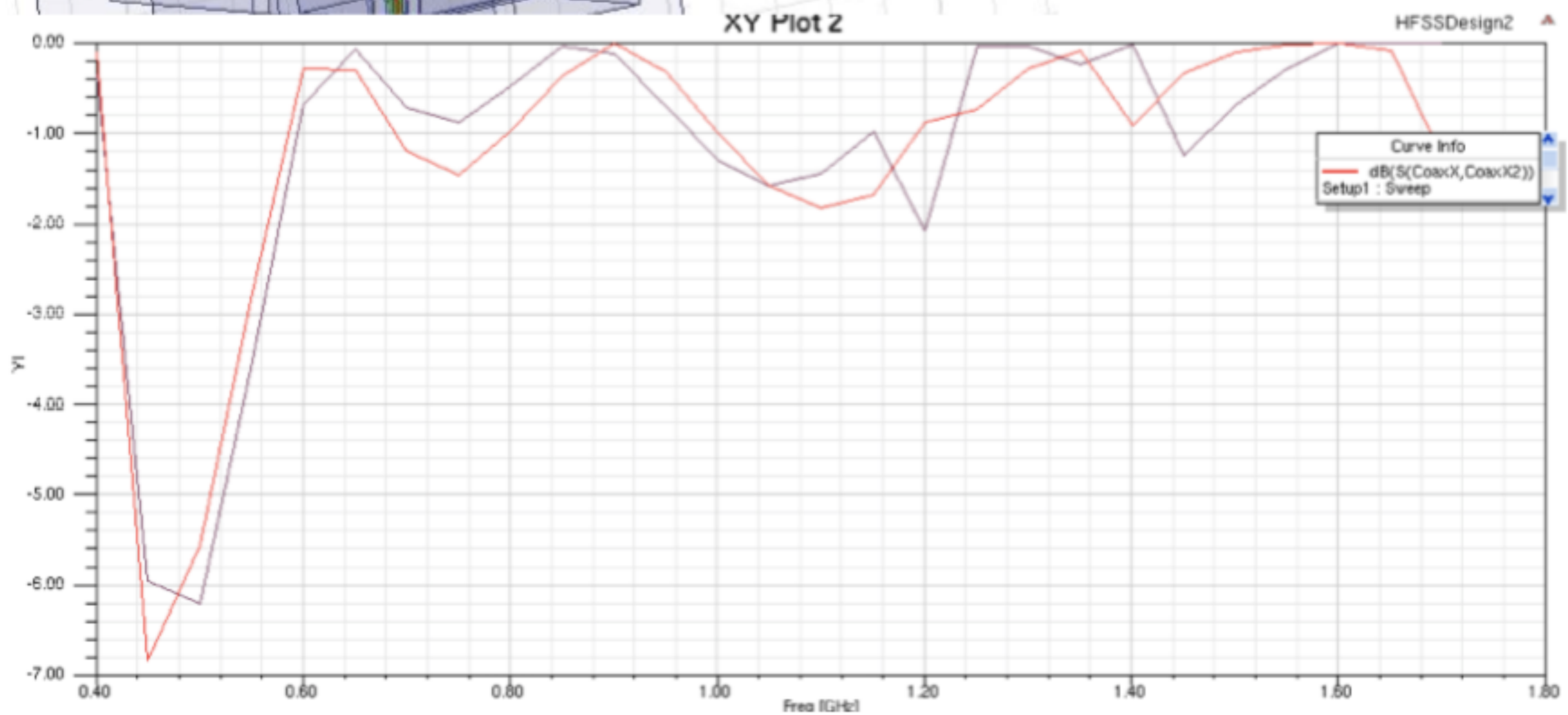


XY Plot 1
HFSSDesign1
Curve Info
dB(S(coax_x:1,OMT_aperture:1))
Setup1 : Sweep
dB(S(coax_y:1,OMT_aperture:2))
Setup1 : Sweep
0 dB
-0.6 dB
-4 dB
S21 (dB)
-1.00
-2.00
-3.00
-4.00
-5.00
0.40
0.80
1.00
1.20
1.40
Freq [GHz]
0.6 GHz
1.5 GHz

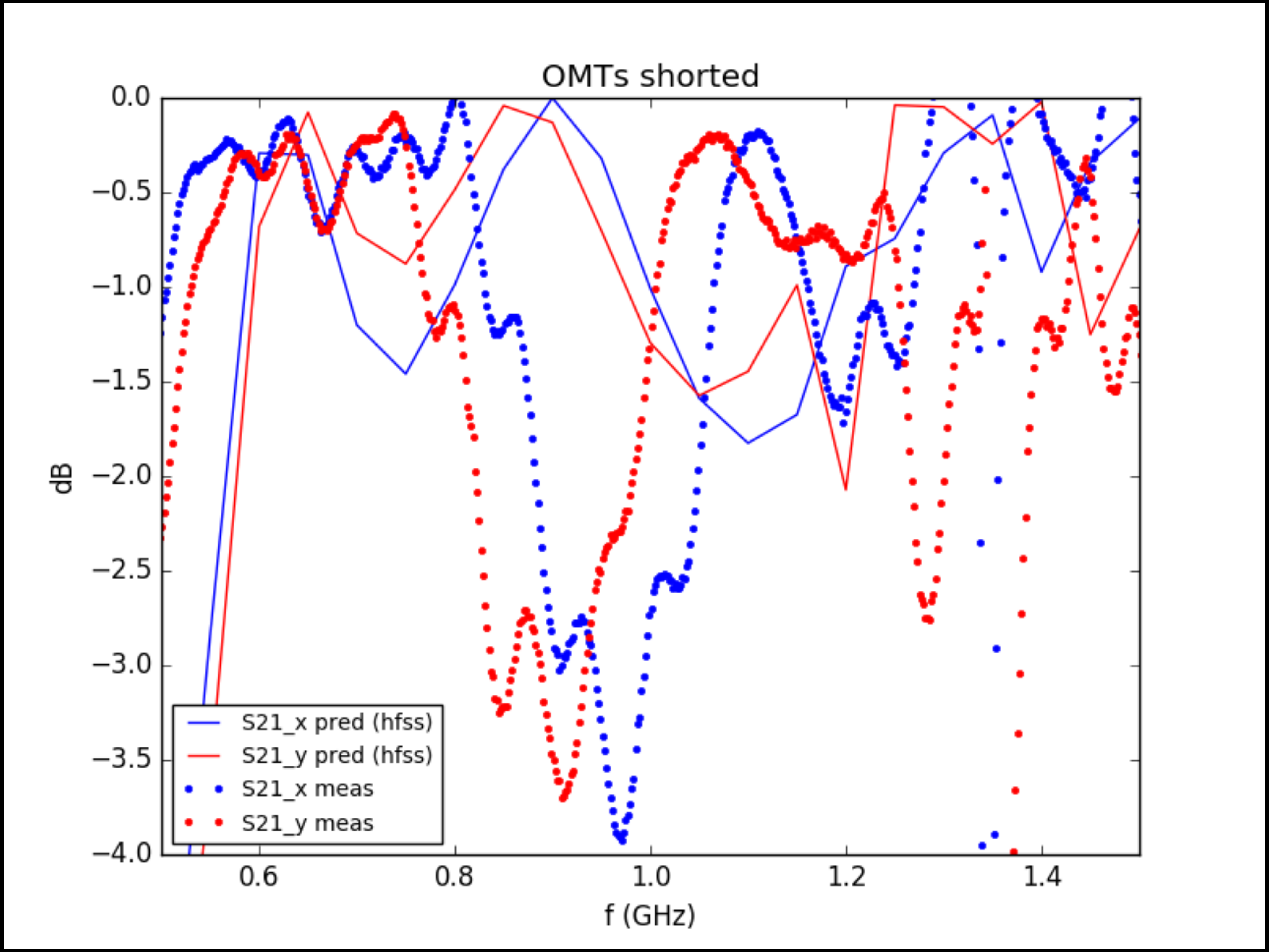
Two OMTs bolted together

compare to measurements

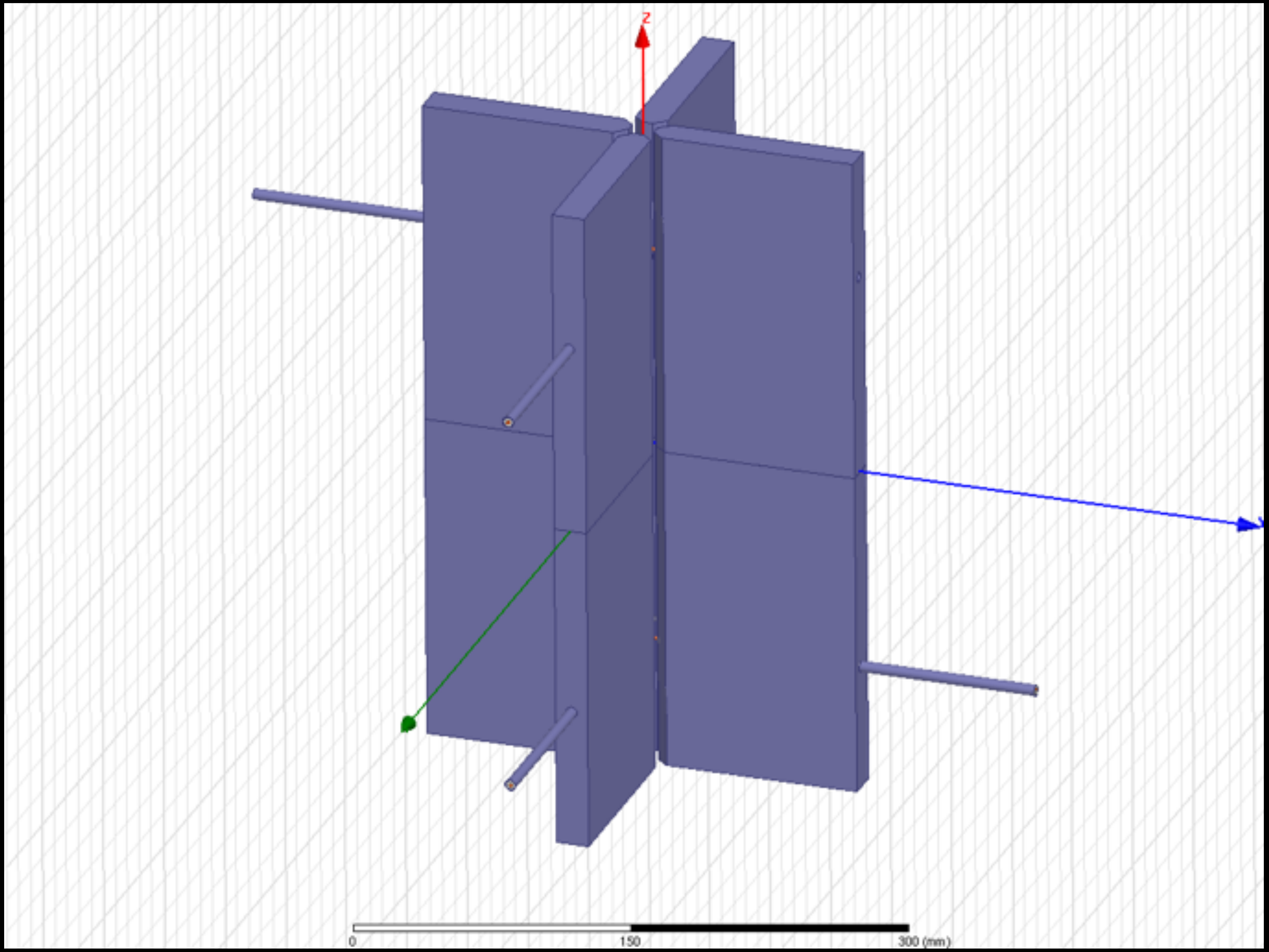




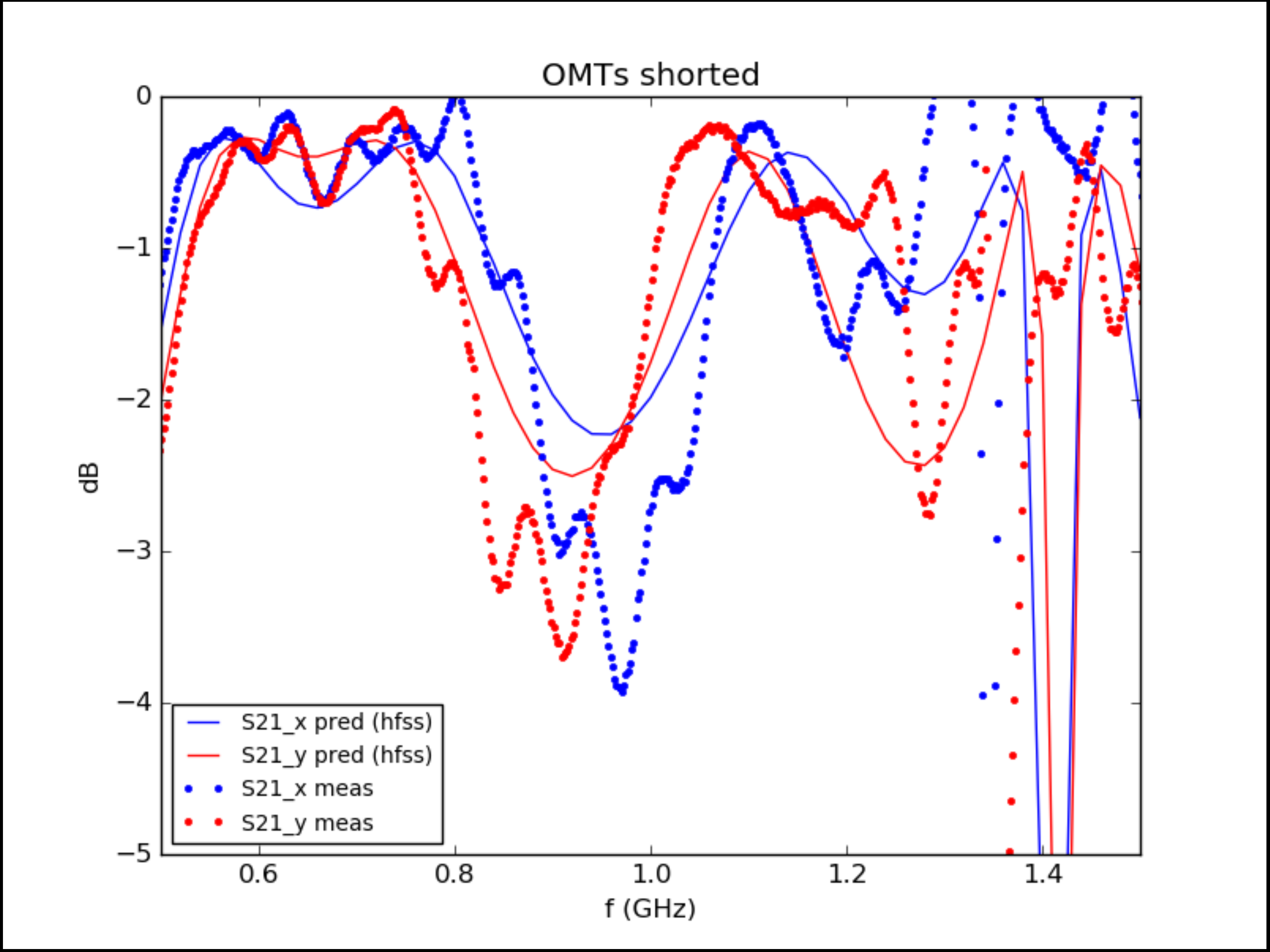
Measured vs. simulated



Include coax dialectric properly in model



Measured vs. simulated



Good that simulations more or less match measurements now, but S_{21} is very low, mostly due to loss in the coax. This is a problem.

Loss in coax

Passive devices produce thermal noise:

$T_N \sim T_{physical} * \text{loss}$

where loss = 1 - (S11 + S21)

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This is true even when input power = 0. The source of the noise is thermal motions of electrons dissipating power in the not-perfectly-conducting waveguide surfaces, and so has the same origin as the resistive loss of the system (Johnson-Nyquist noise).

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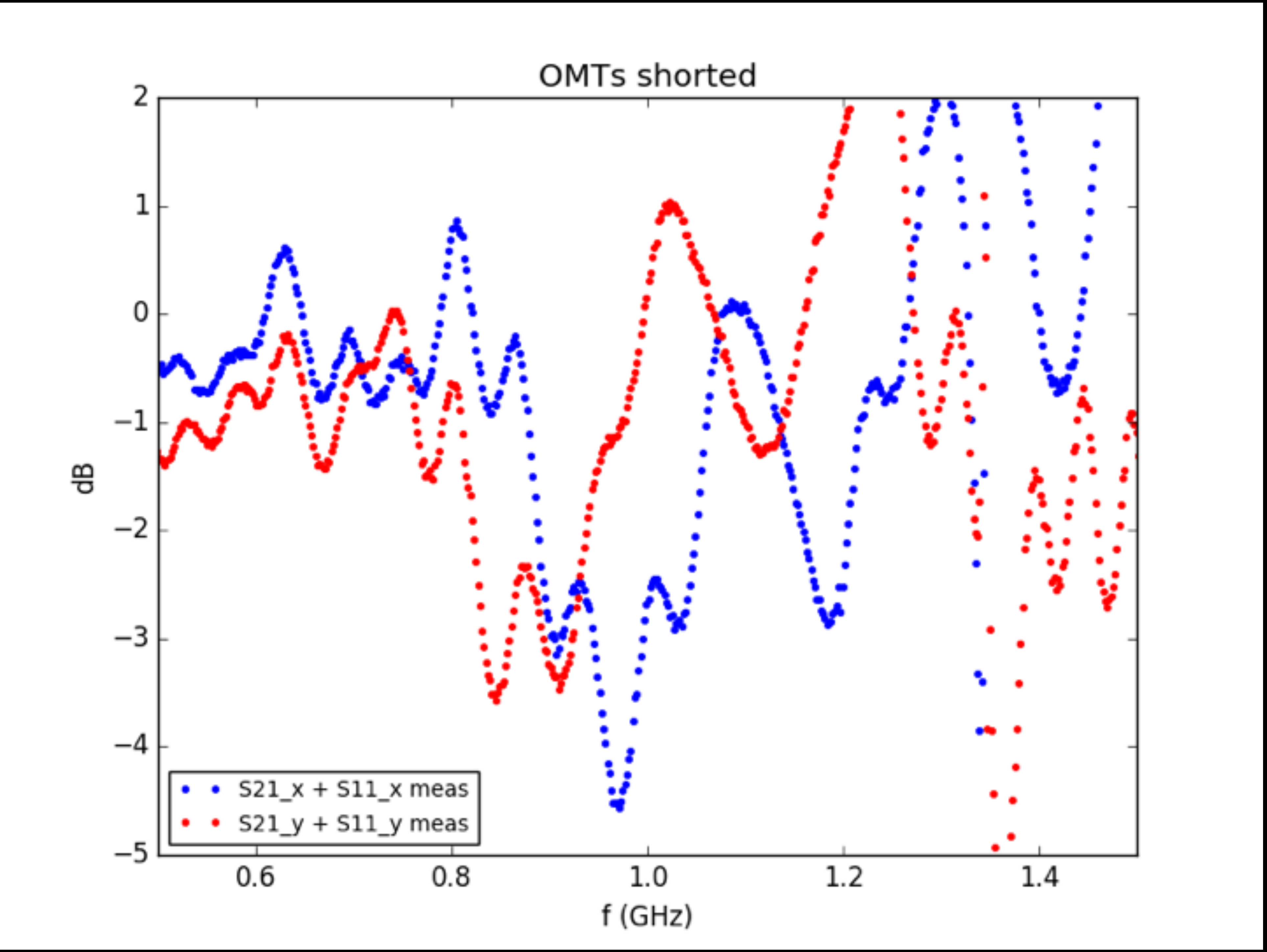
A ~20% loss of signal power degrades the ultimate S/N by same amount, which we don't necessarily care too much about. But additive noise of 300 K * 0.2 = 60 K will degrade S/N by large factor (because we expect sky temperature << 60 K at 1 GHz, and LNA noise temperature is ~20 K).

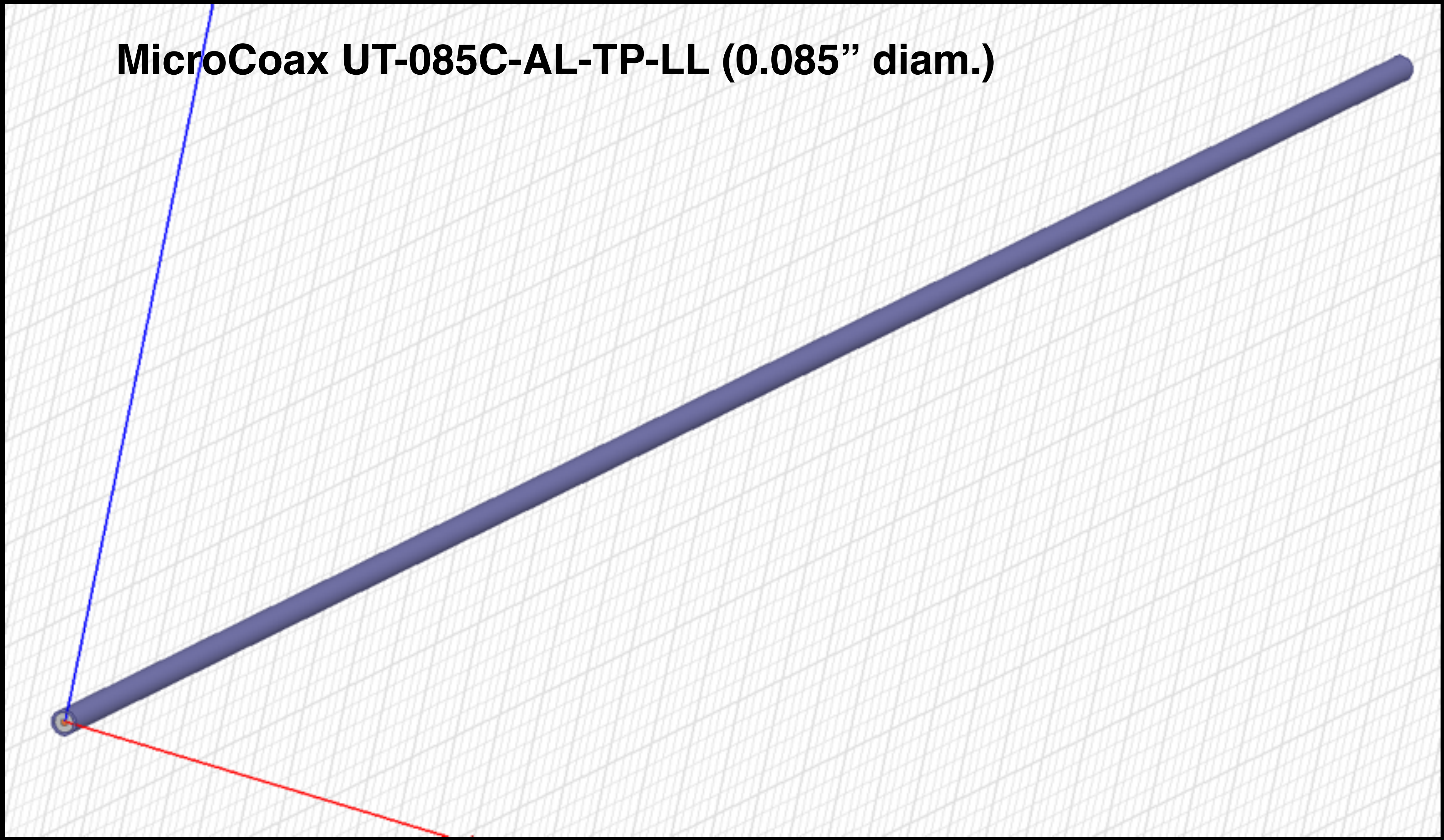
Measured loss with VNA



implies significant loss, but S11+S22>1 also implies a large measurement systematic

Simulated loss including coax dialectric

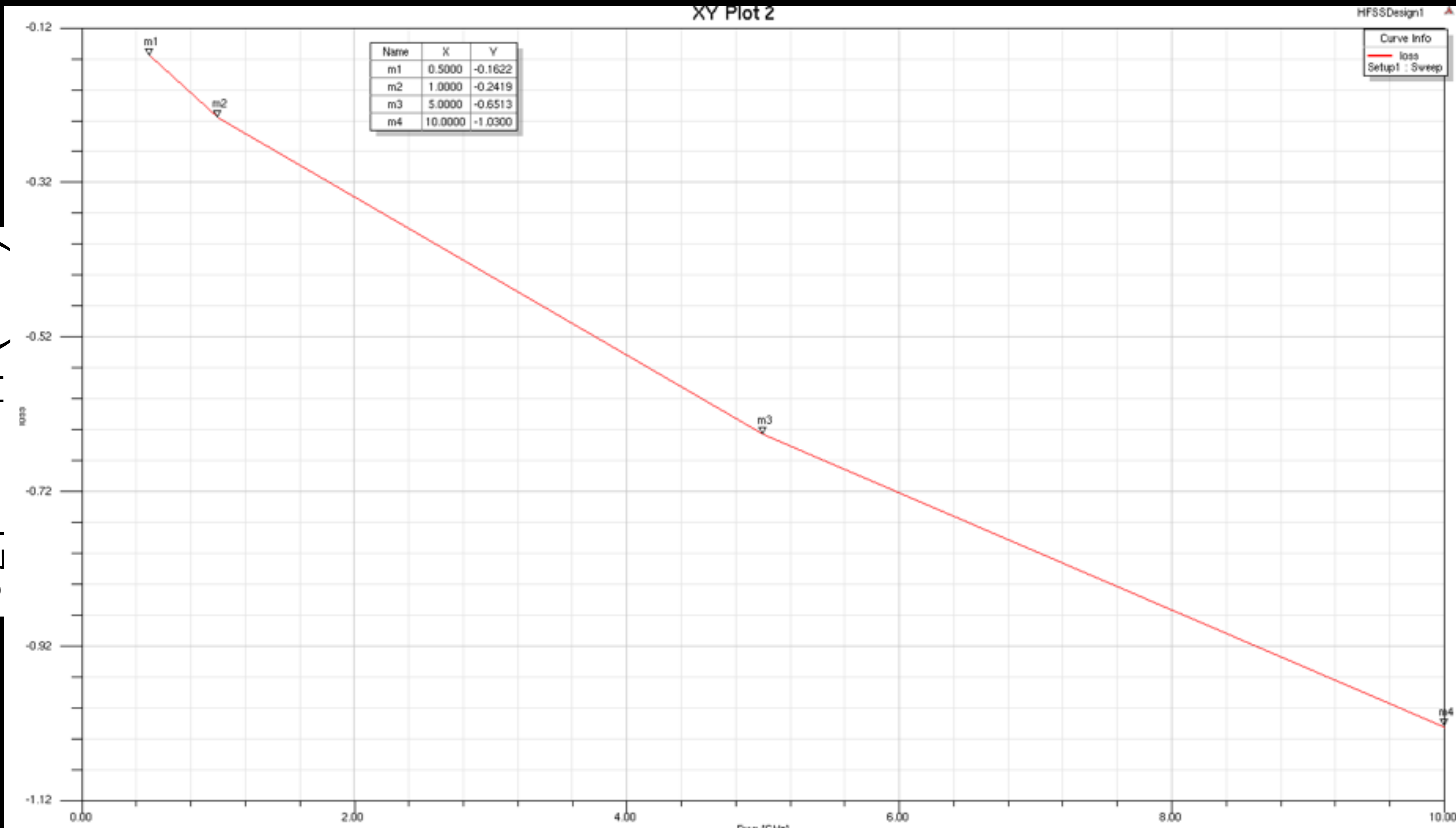
1 ft of coax (loss in dB scales linearly with length)



Simulated loss including coax dialectric

checked against data sheet, matches

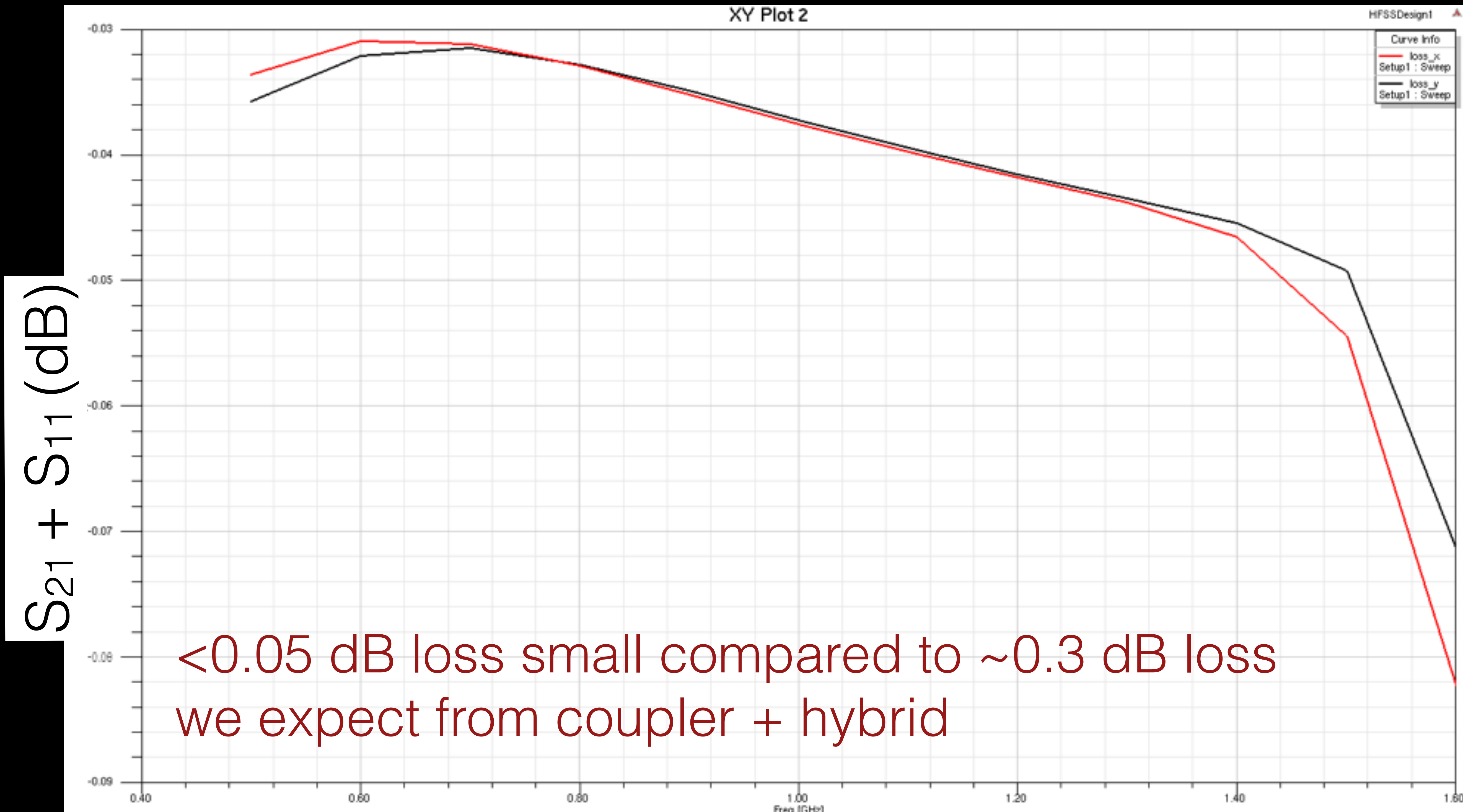
$S_{21} + S_{11}$ (dB)



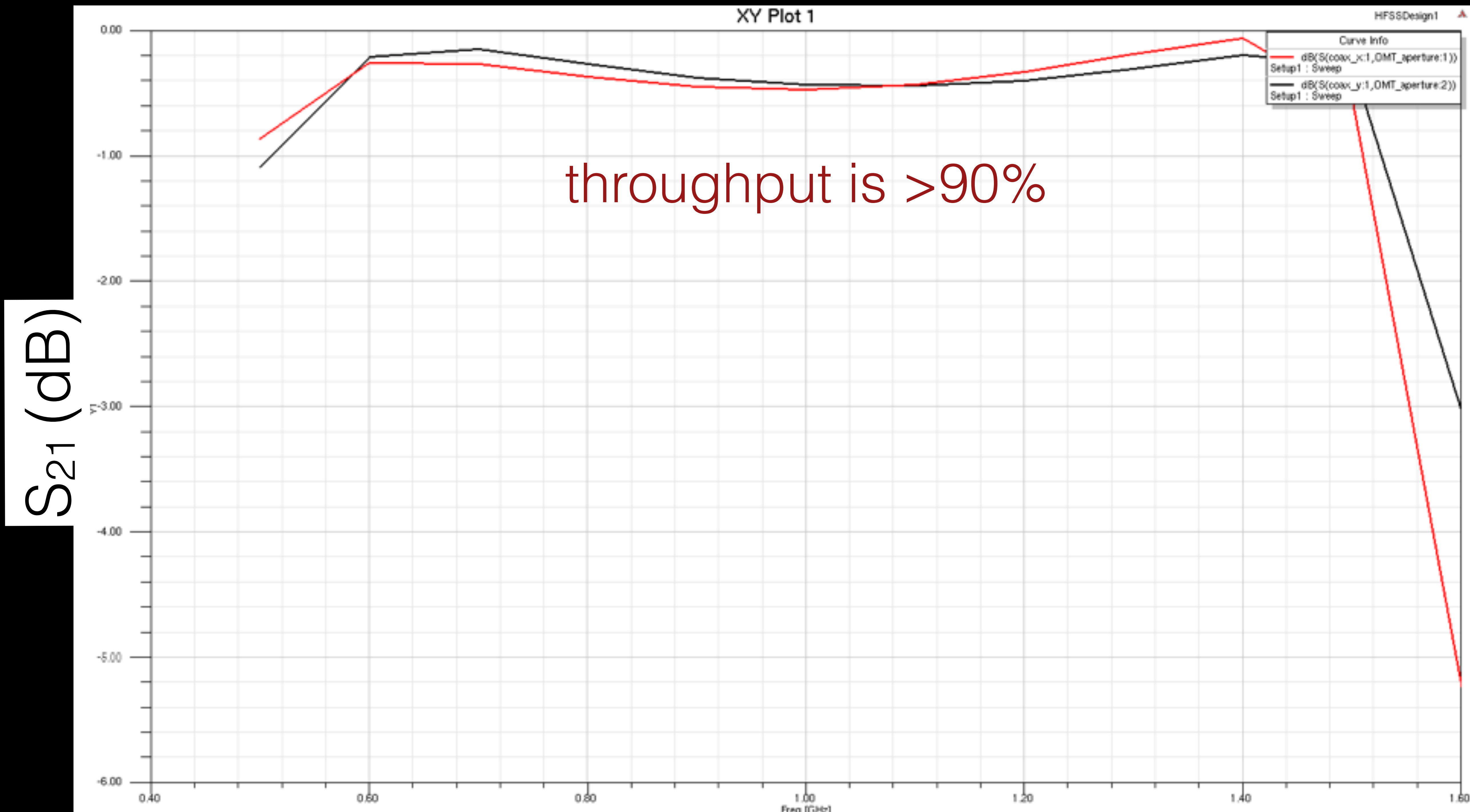
Simulated loss including coax dialectric

- ~1 dB of loss of OMT as designed contributes ~60 K noise temperature
- Switch to larger diameter coax (UT-250C-ULL)

OMT loss with 0.25” diam. coax

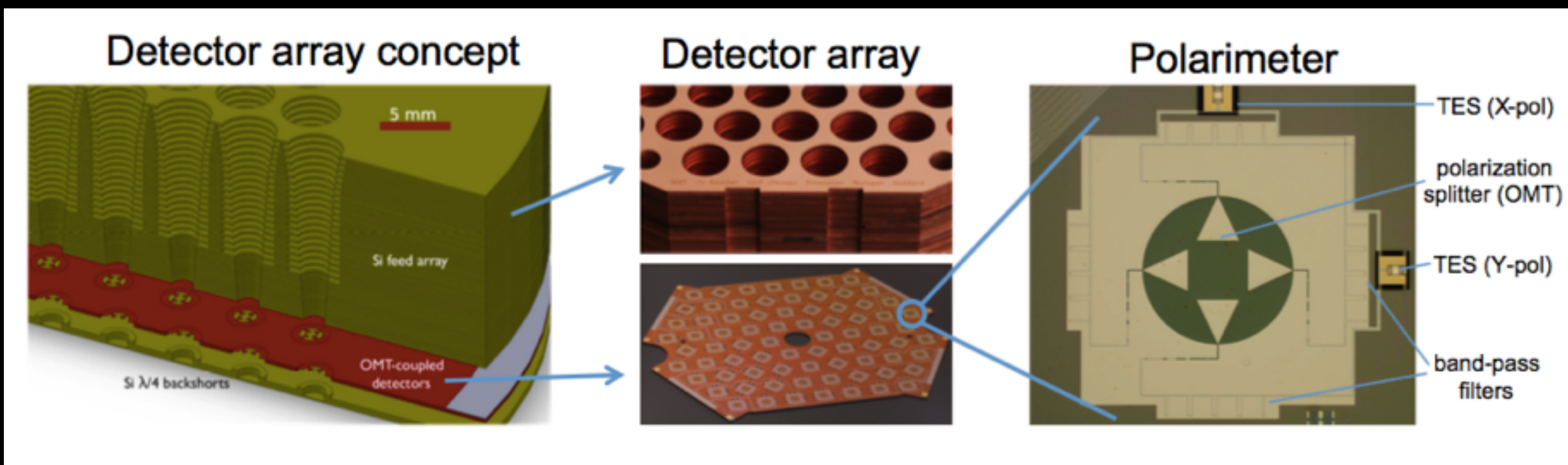


OMT S21 with 0.25” diam. coax



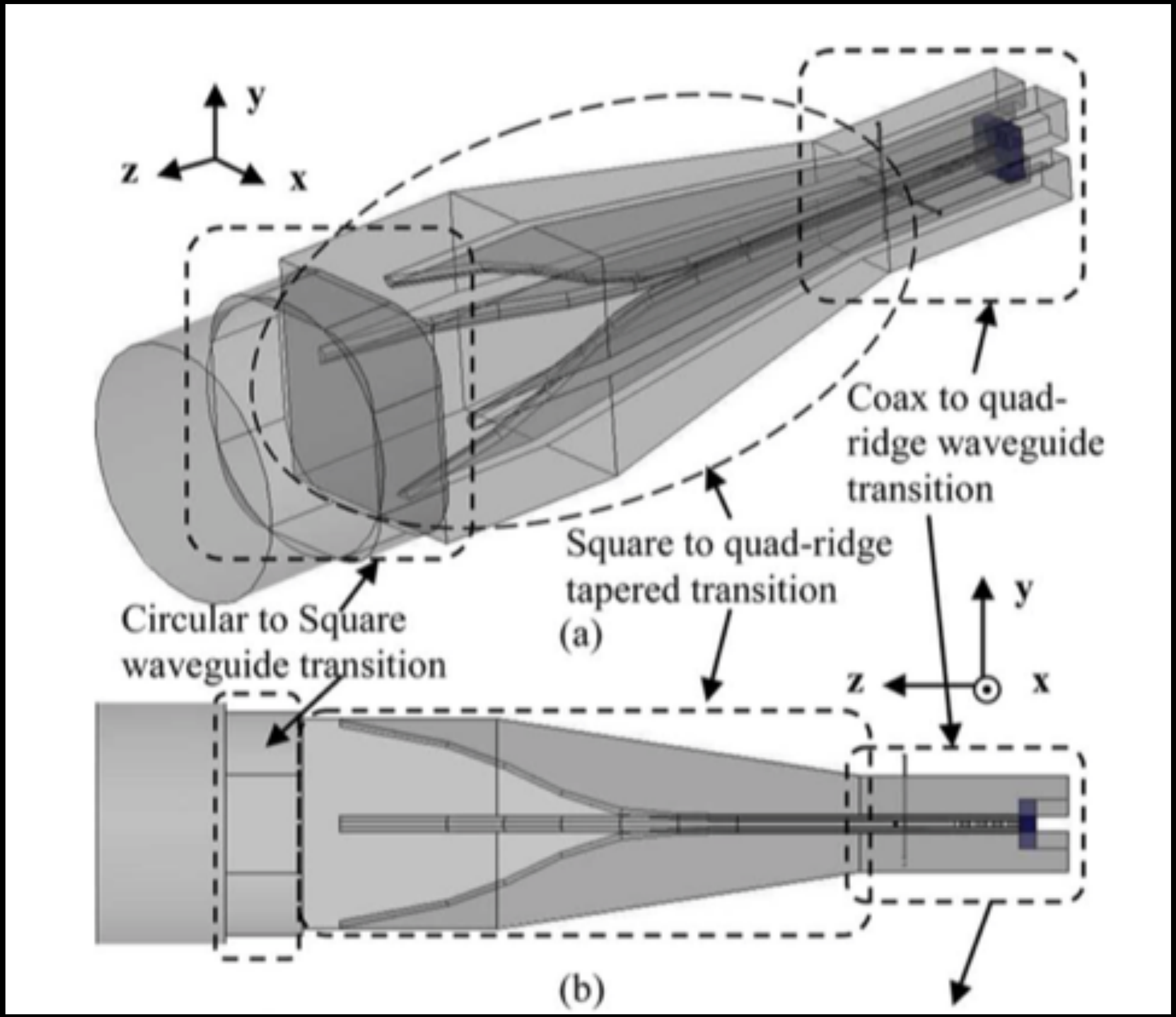
Now need to add transition

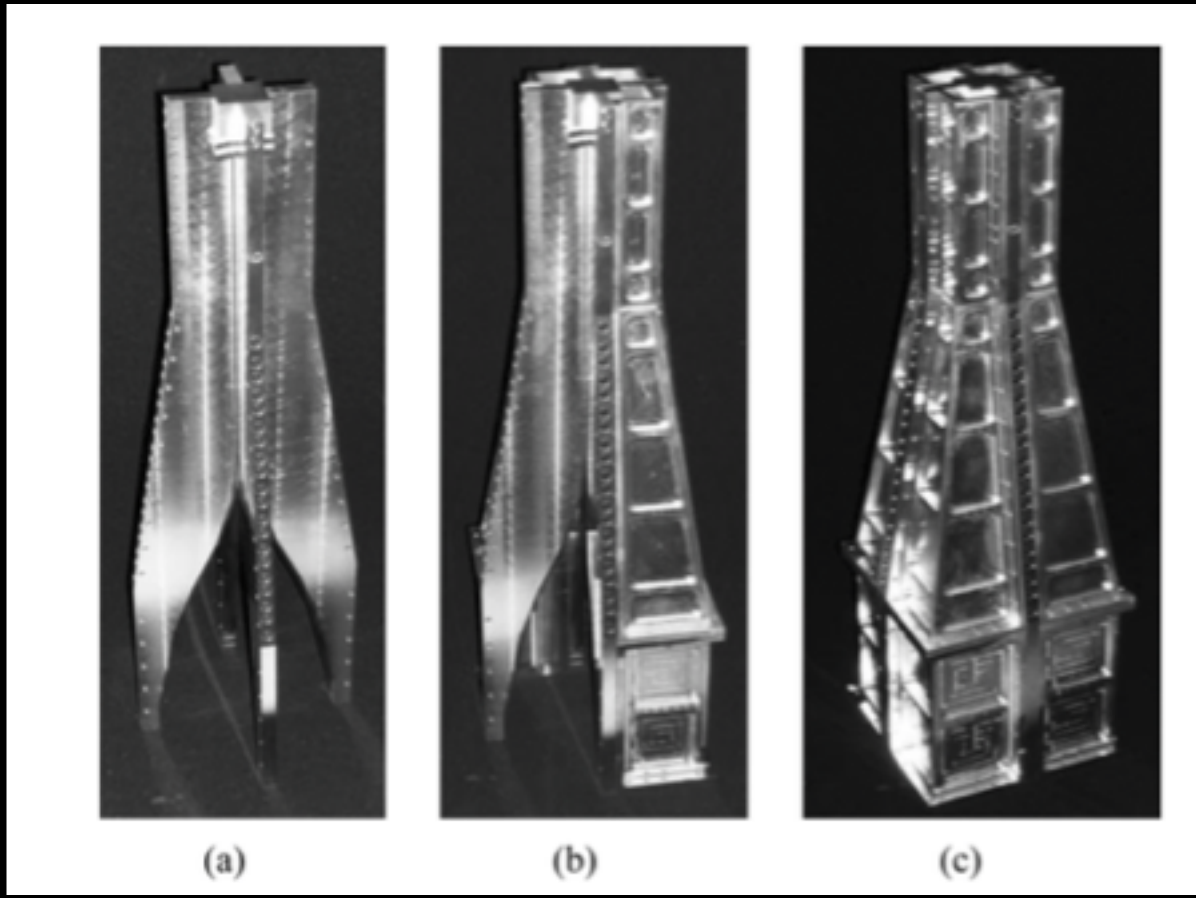
OMT was based on a scaled version of the ACTpol OMT



McMahon et al, 2011

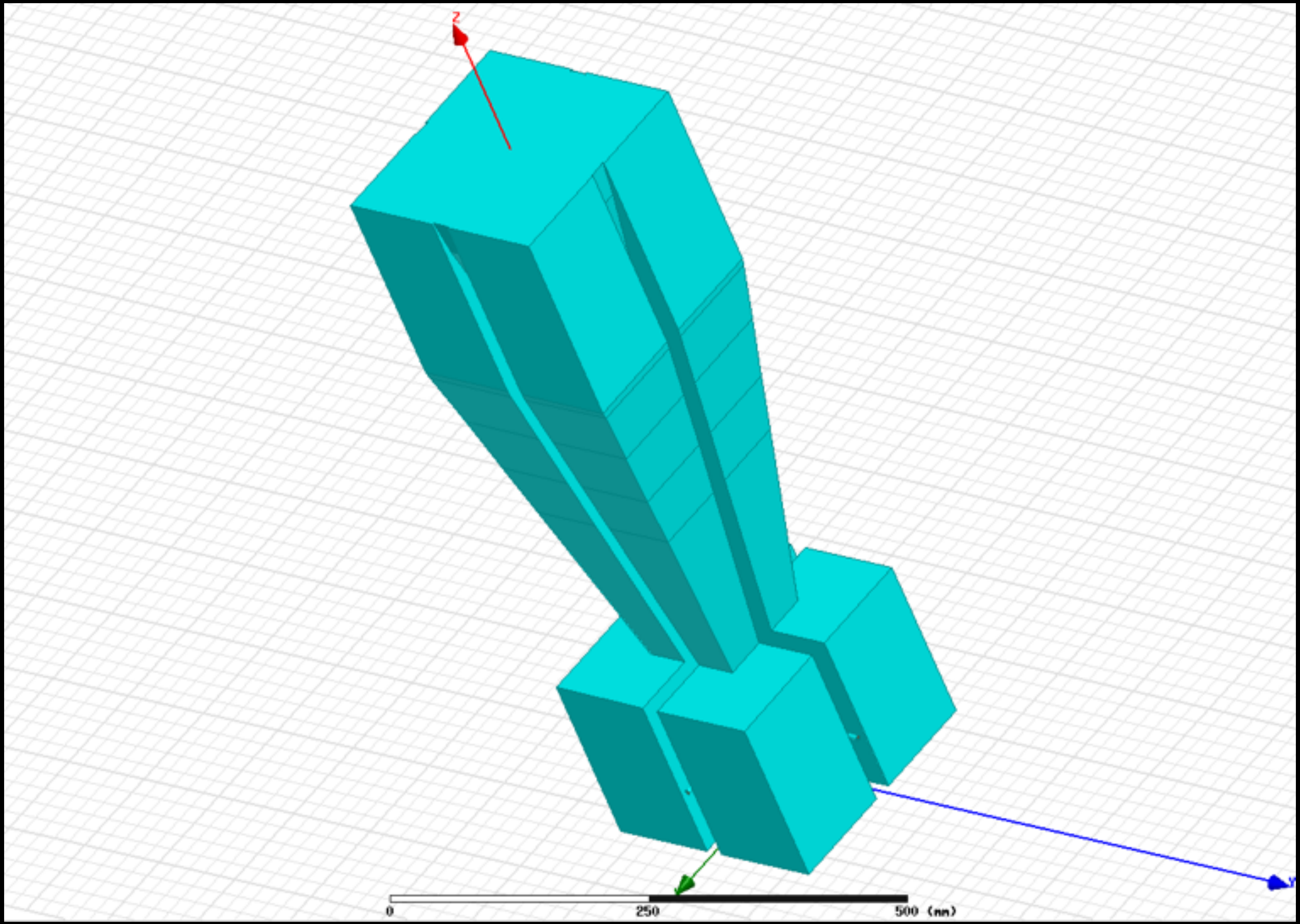
The idea was to design a transition based on a scaled VLA design for an octave bandwidth L-band OMT + transition(1-2 GHz)





Coutts, 2011

OMT + VLA transition



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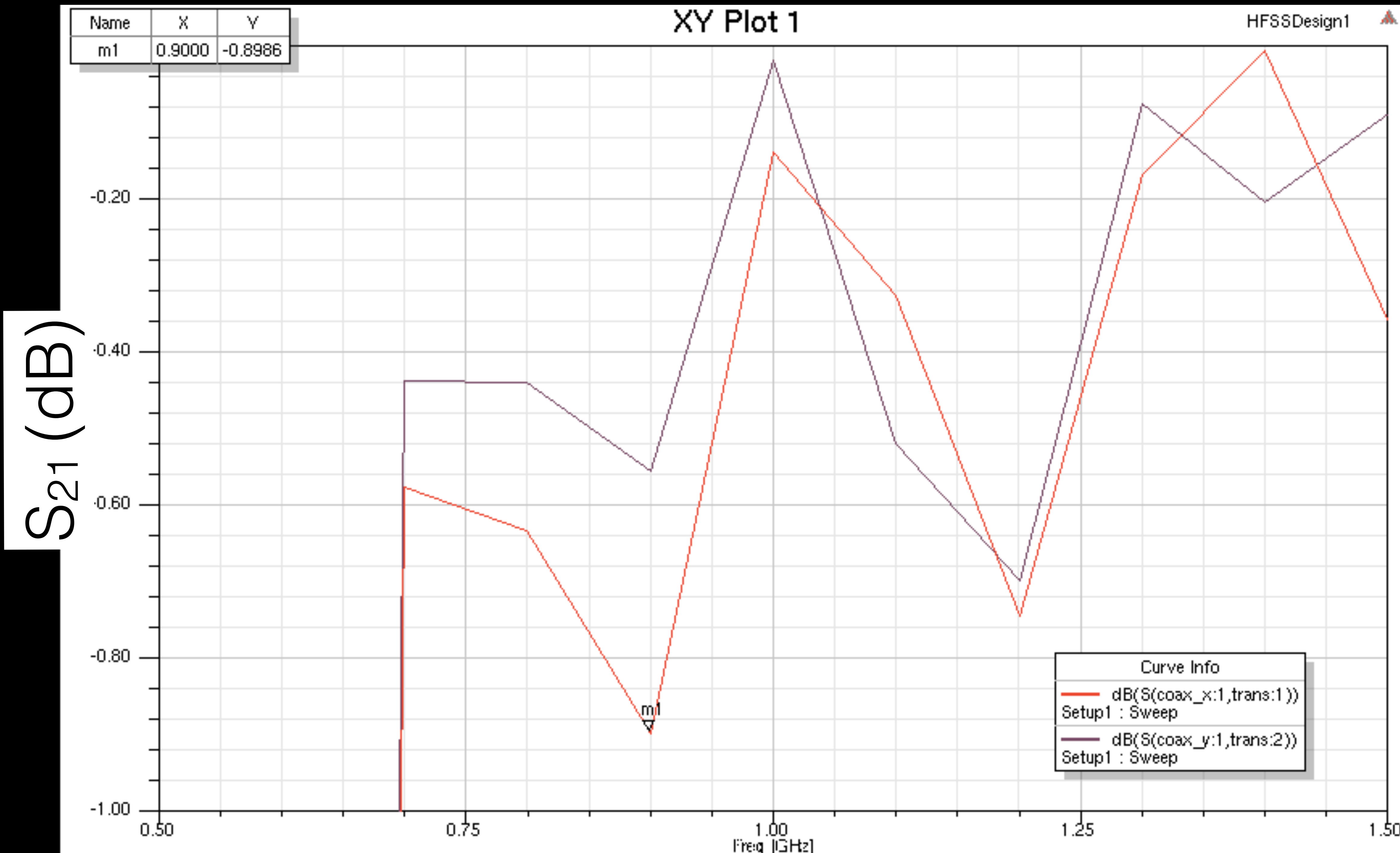

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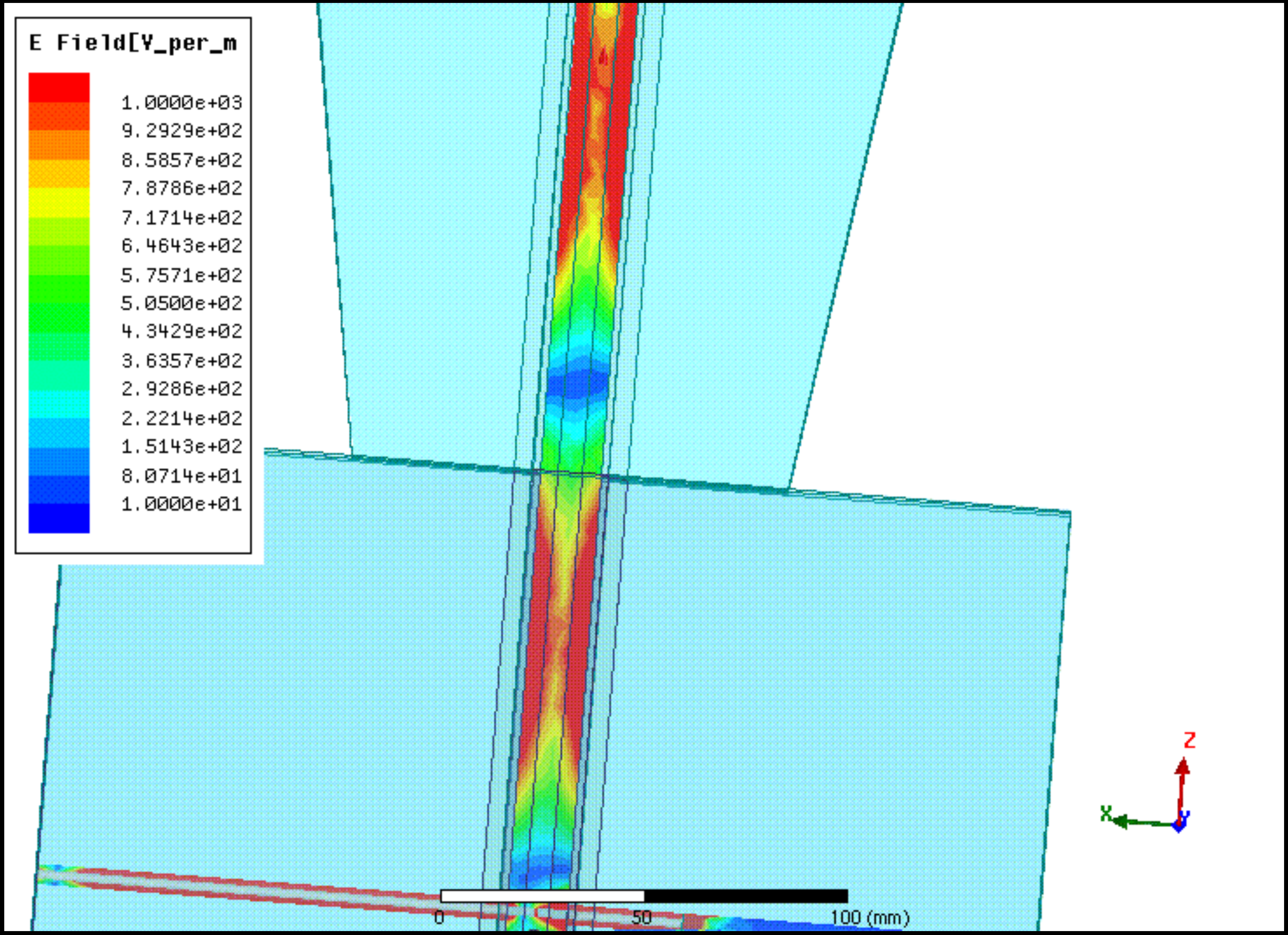
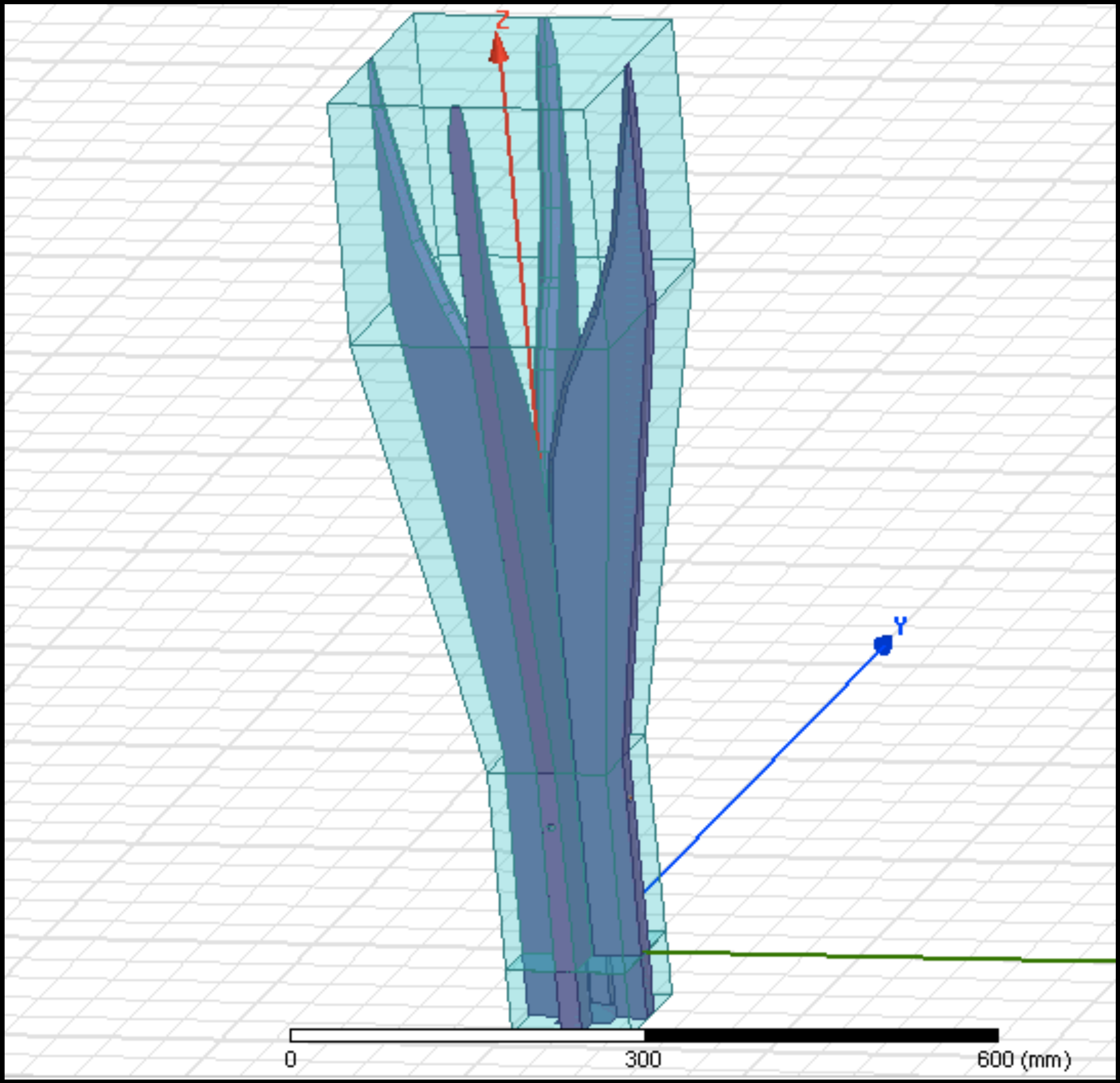


Could probably futz around with transition profile enough to make work with existing OMT (and I did try a bit), but Jeff and I decided just to ditch the original OMT and do a modified version of the VLA OMT + VLA transition

Has advantage of being much more compact (~4” OMT outer dimension vs. ~10”)

VLA OMT + VLA transition (scaled)



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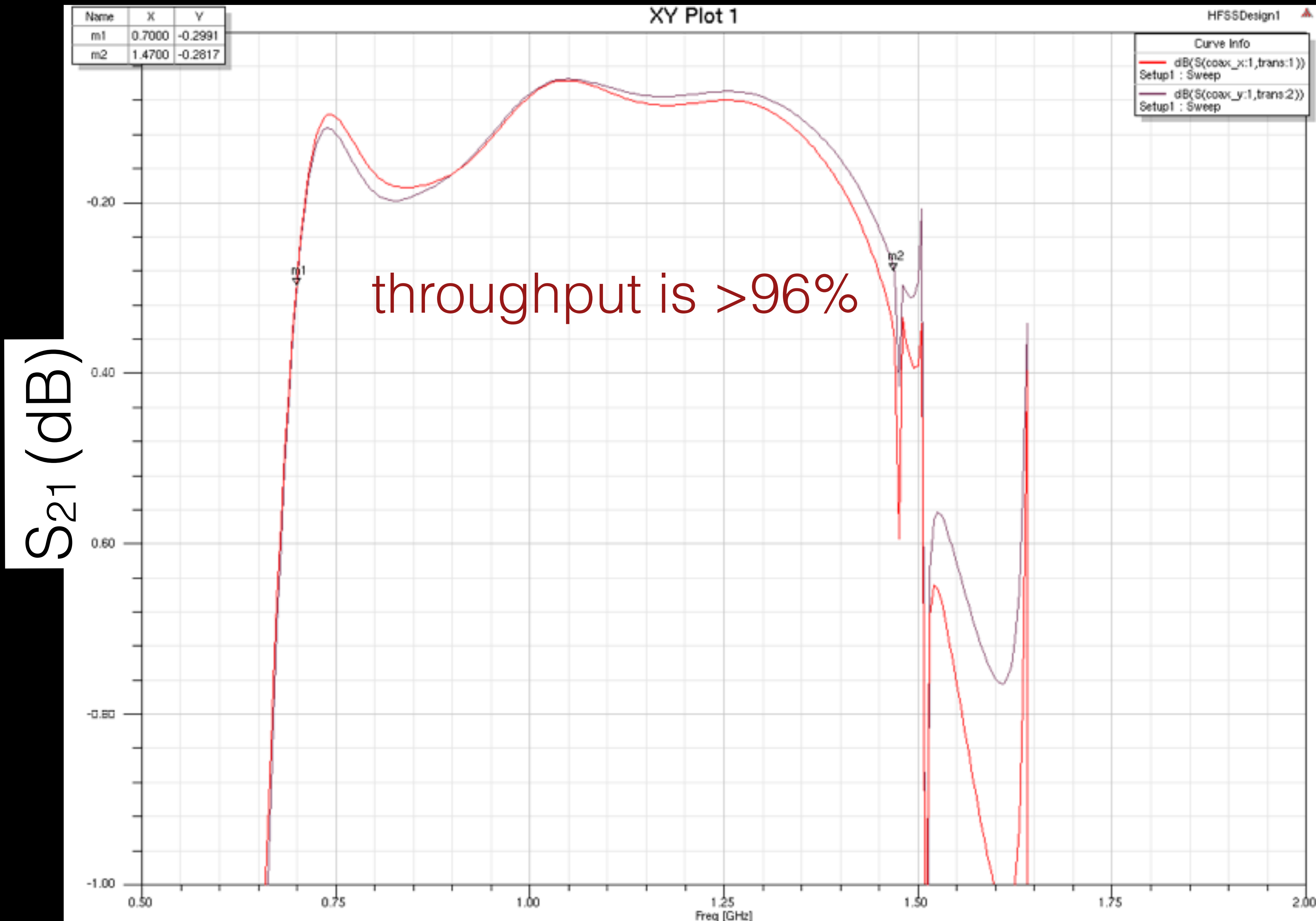


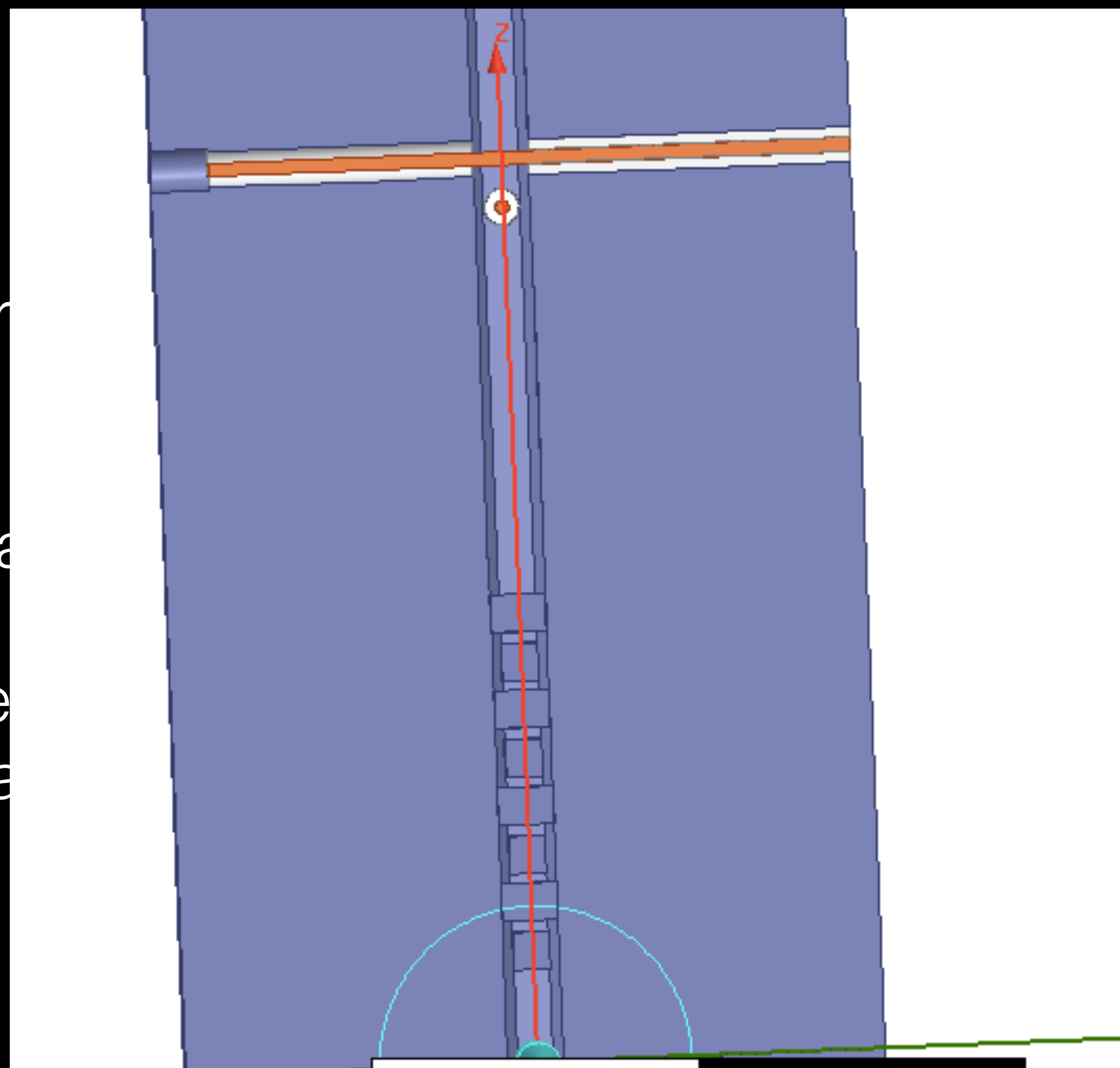
VLA OMT + VLA transition

Modifications:

- scale by factor 1.43 to move from 1-2 GHz to 0.7 - 1.4 GHz
- change ridge thickness to stock thickness (3/4”)
- increase ridge face width to 0.26” to accommodate larger diameter coax
- eliminate complicated blocks and absorber at back in favor of a simple backshort

VLA OMT + VLA transition

Modifications:



- scale by 7 - 1.4 GHz
- change r)
- increase date larger dia
- eliminate ack in favor of a

VLA OMT + VLA transition

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- change r)
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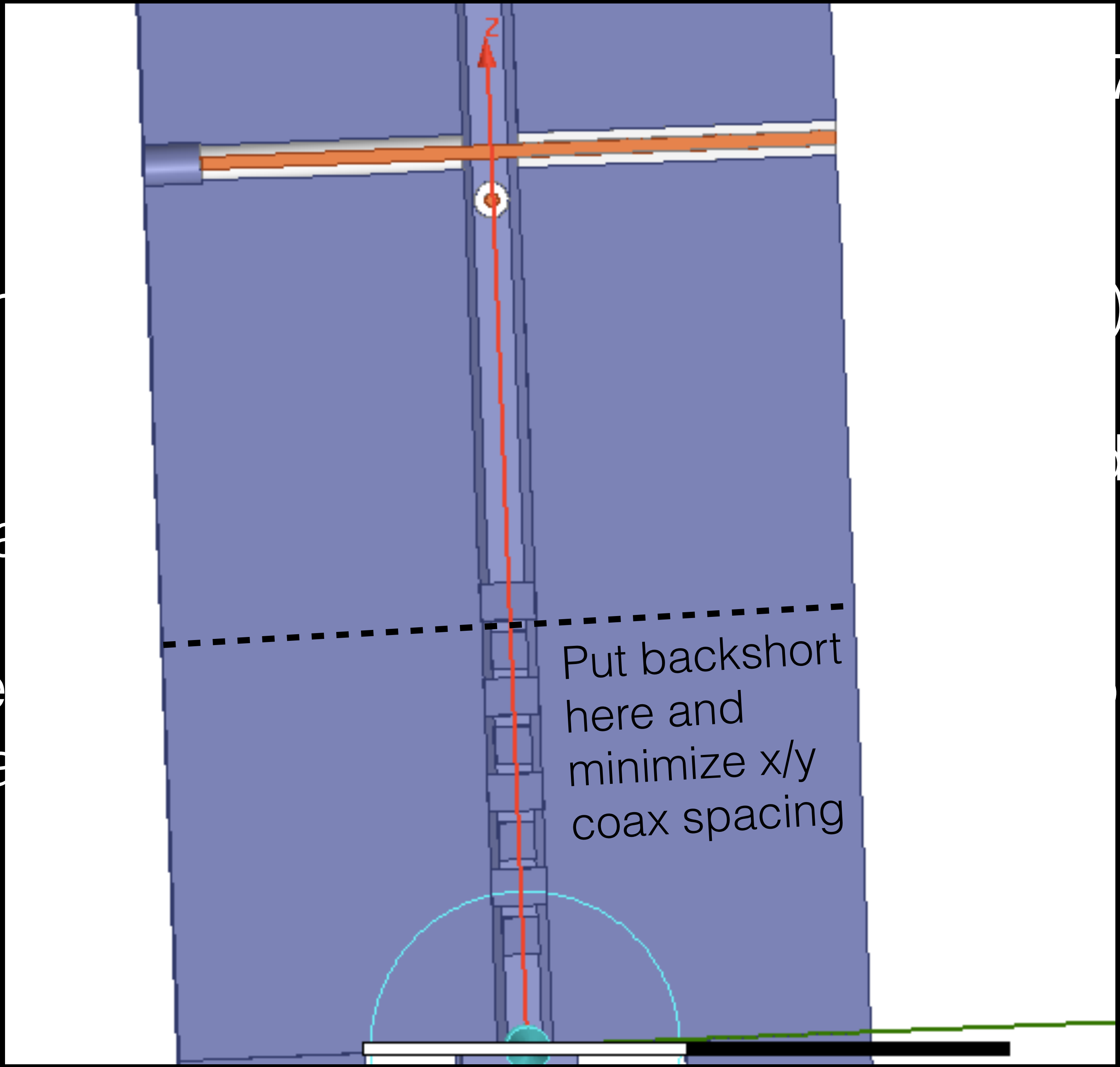
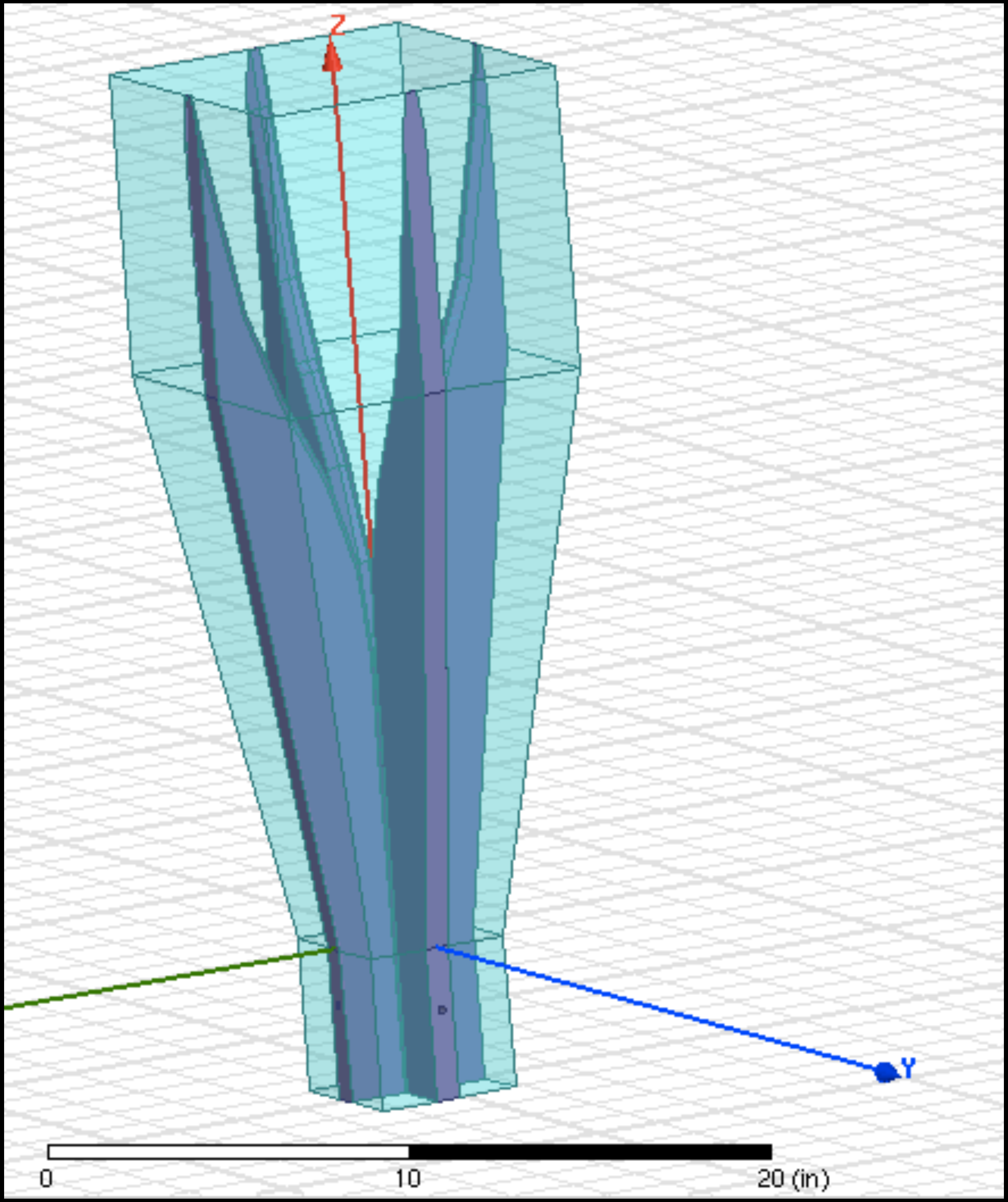
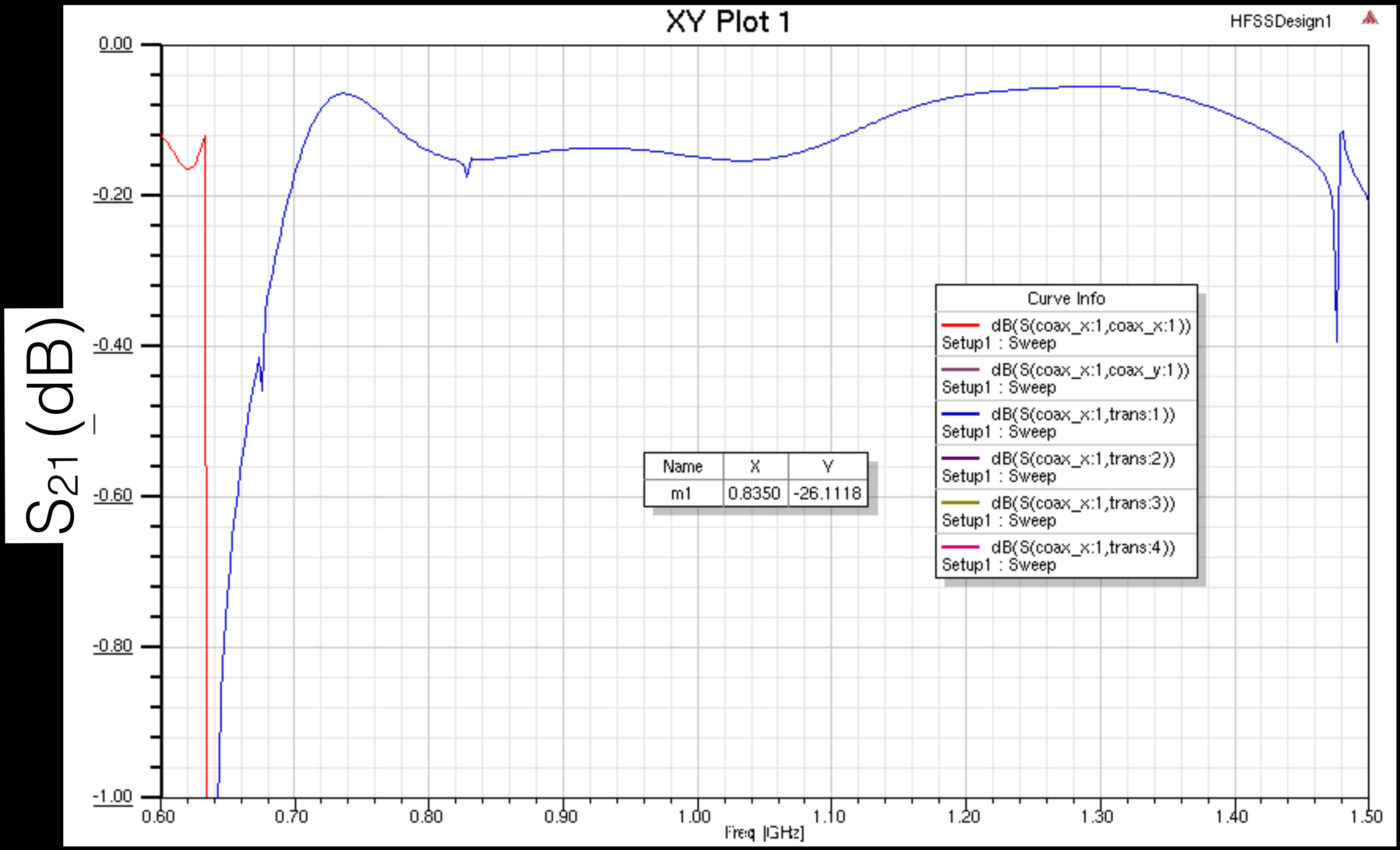


modified VLA OMT + VLA transition



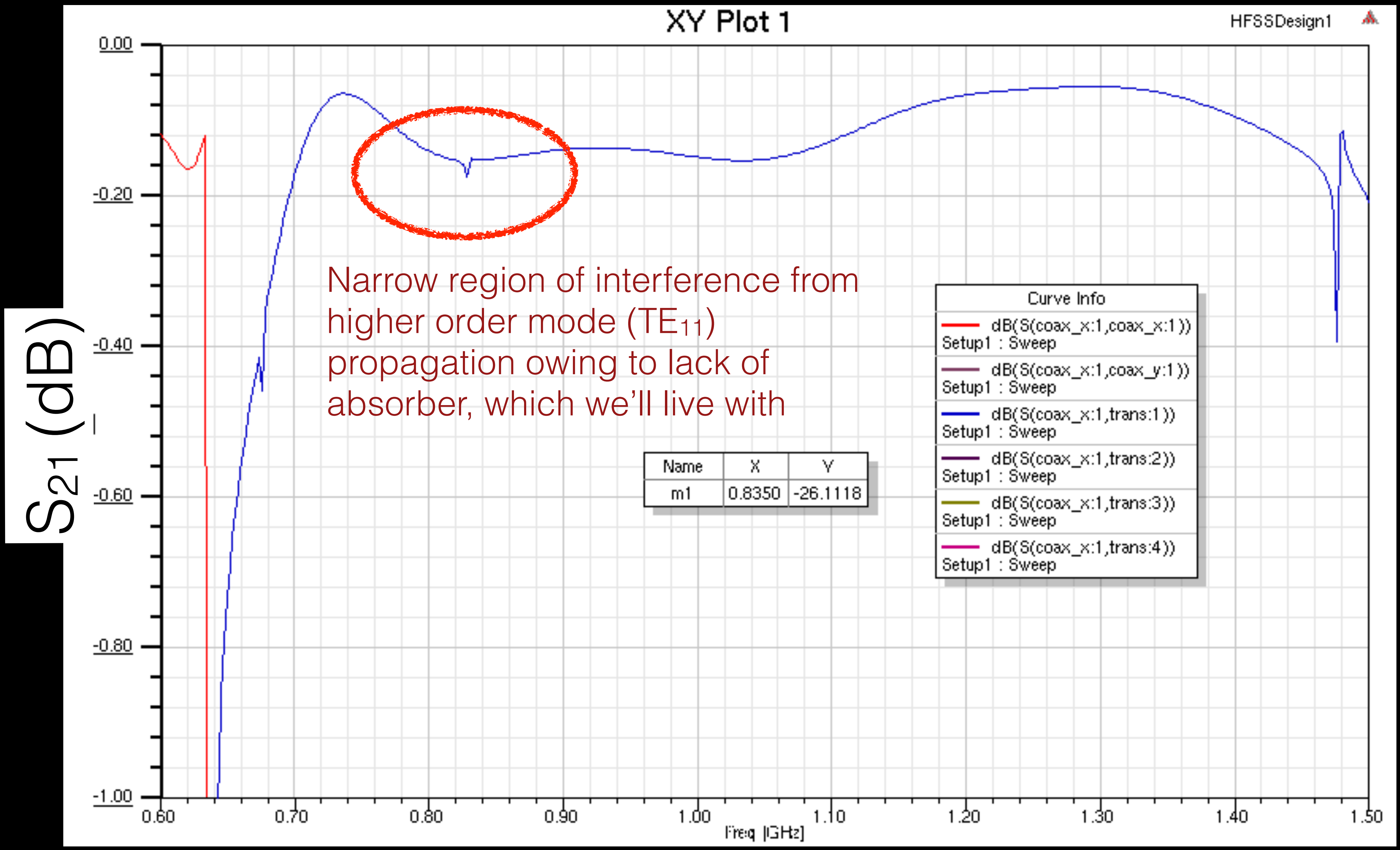
modified VLA OMT + VLA transition

S_{21}



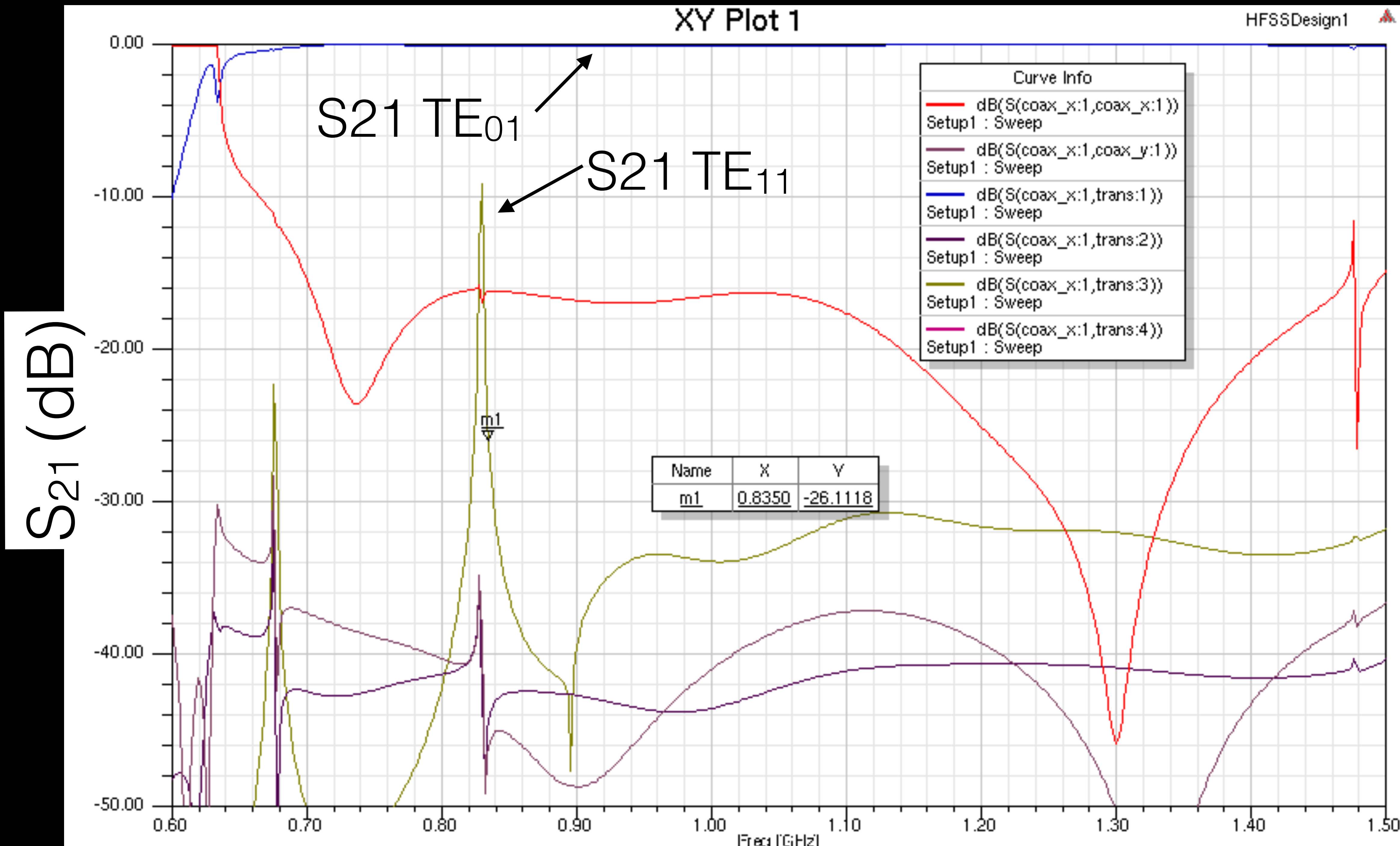
modified VLA OMT + VLA transition

S_{21}



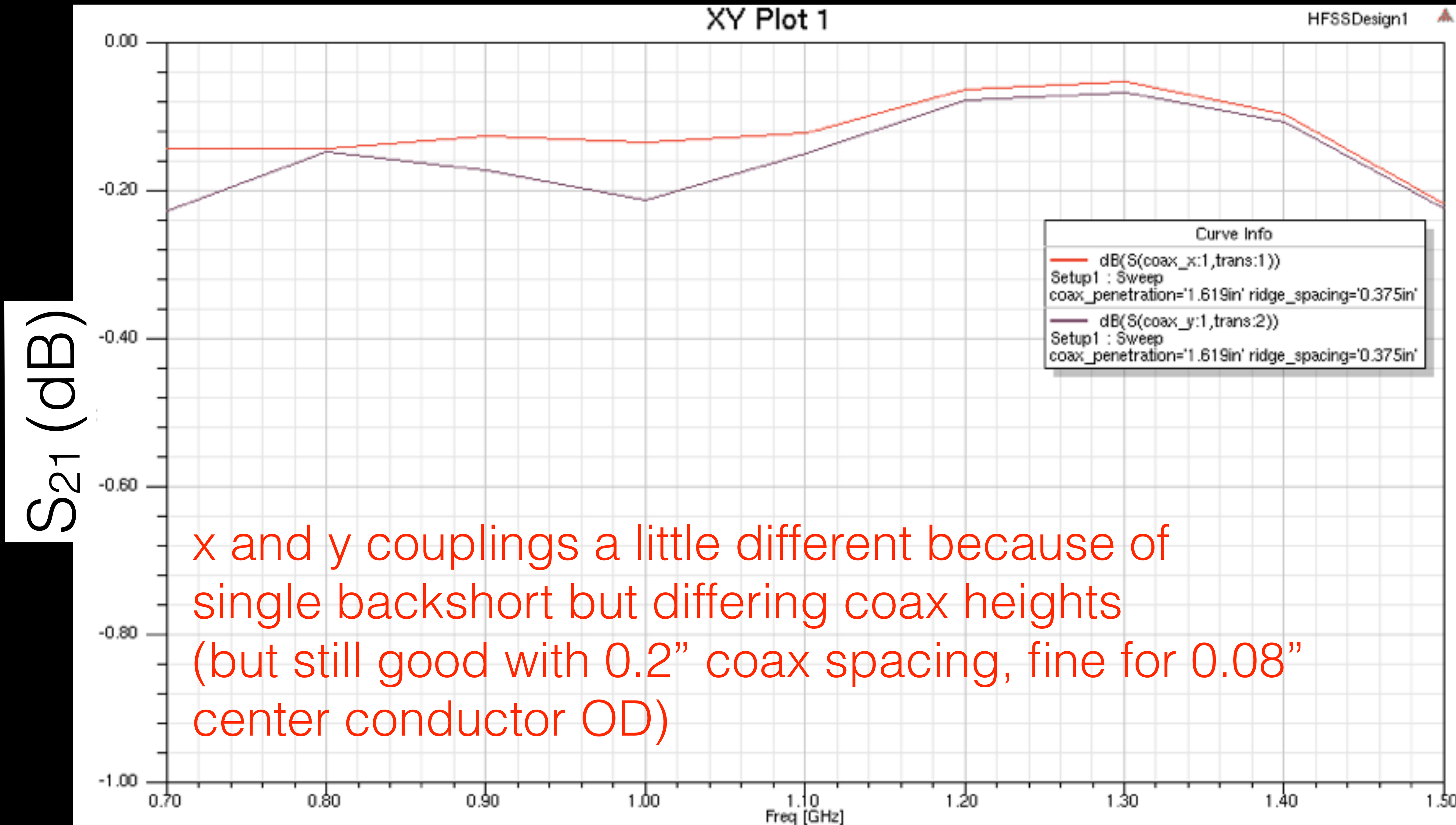
modified VLA OMT + VLA transition

S21



modified VLA OMT + VLA transition

S21



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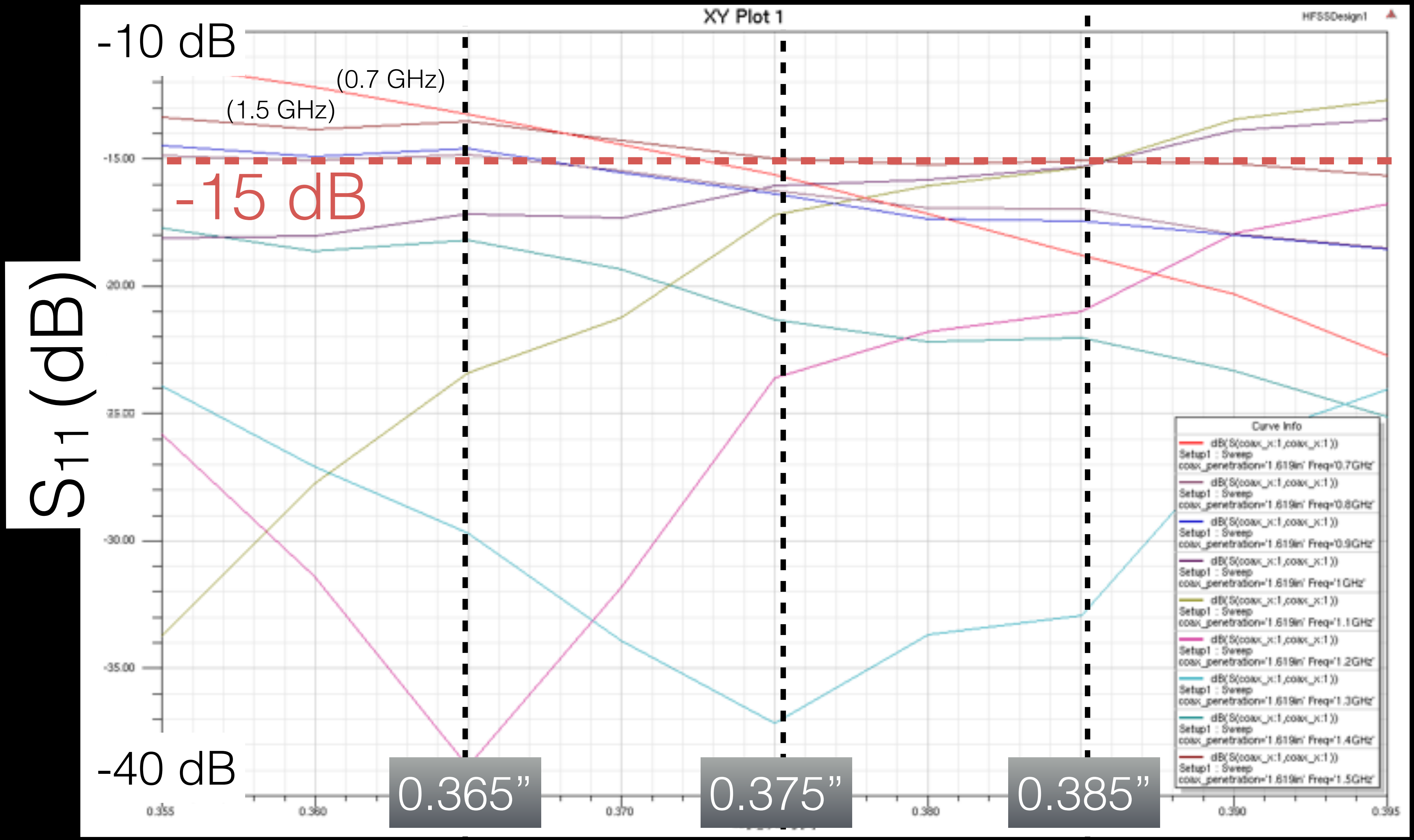
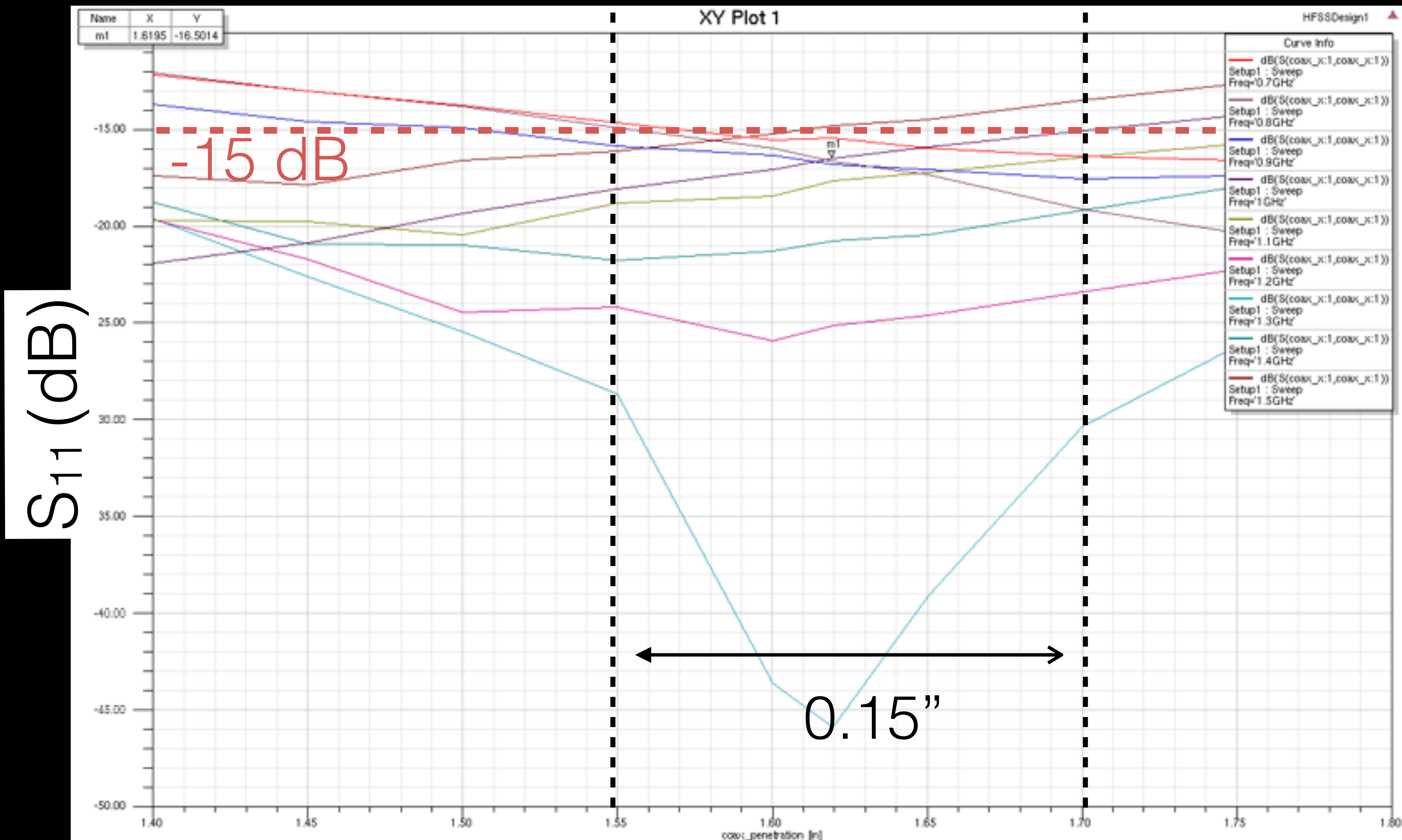


ridge spacing

modified VLA OMT + VLA transition

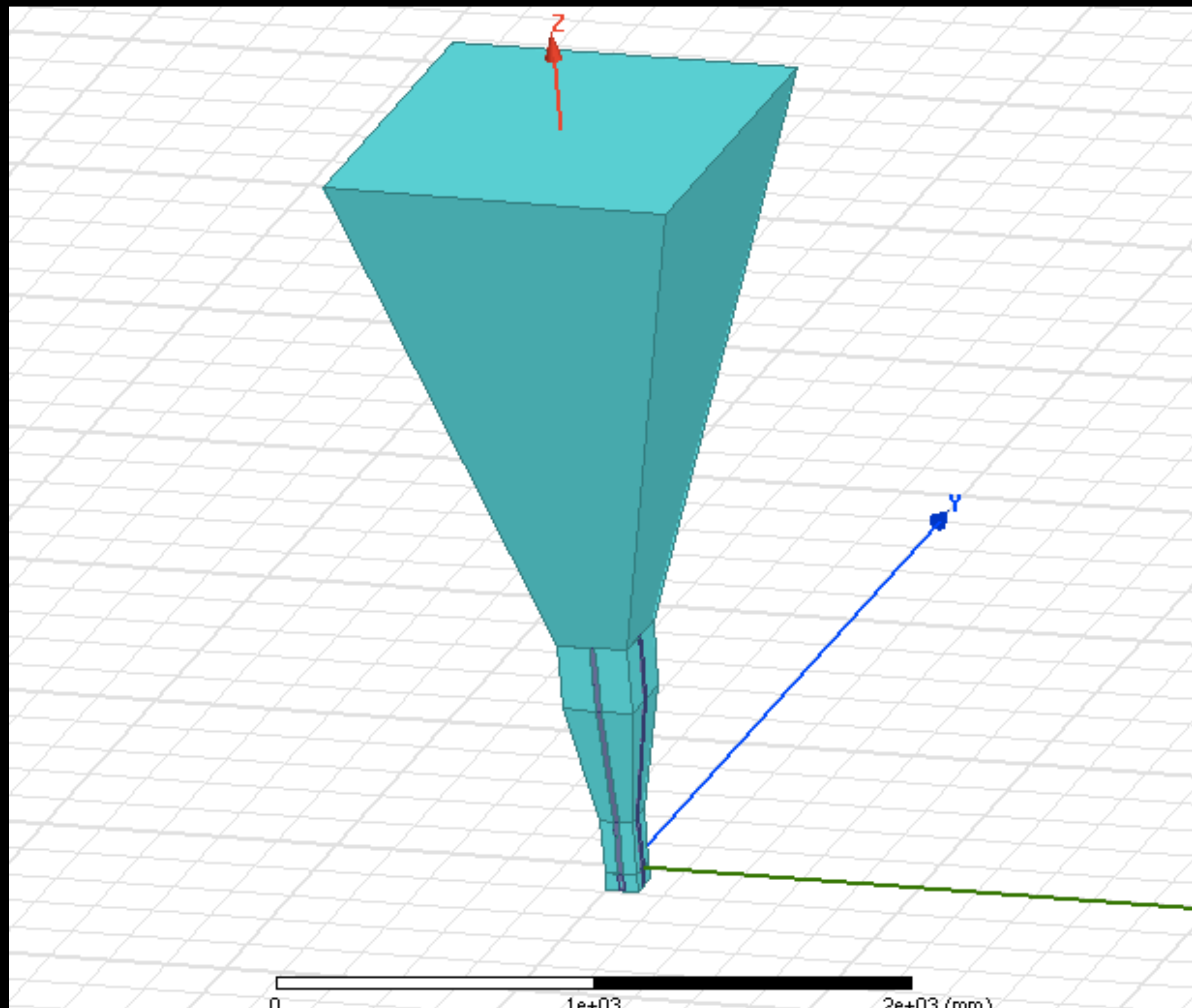
Optimal far ridge coax penetration?



I’m nearly done with the drawings to provide to Jeff.

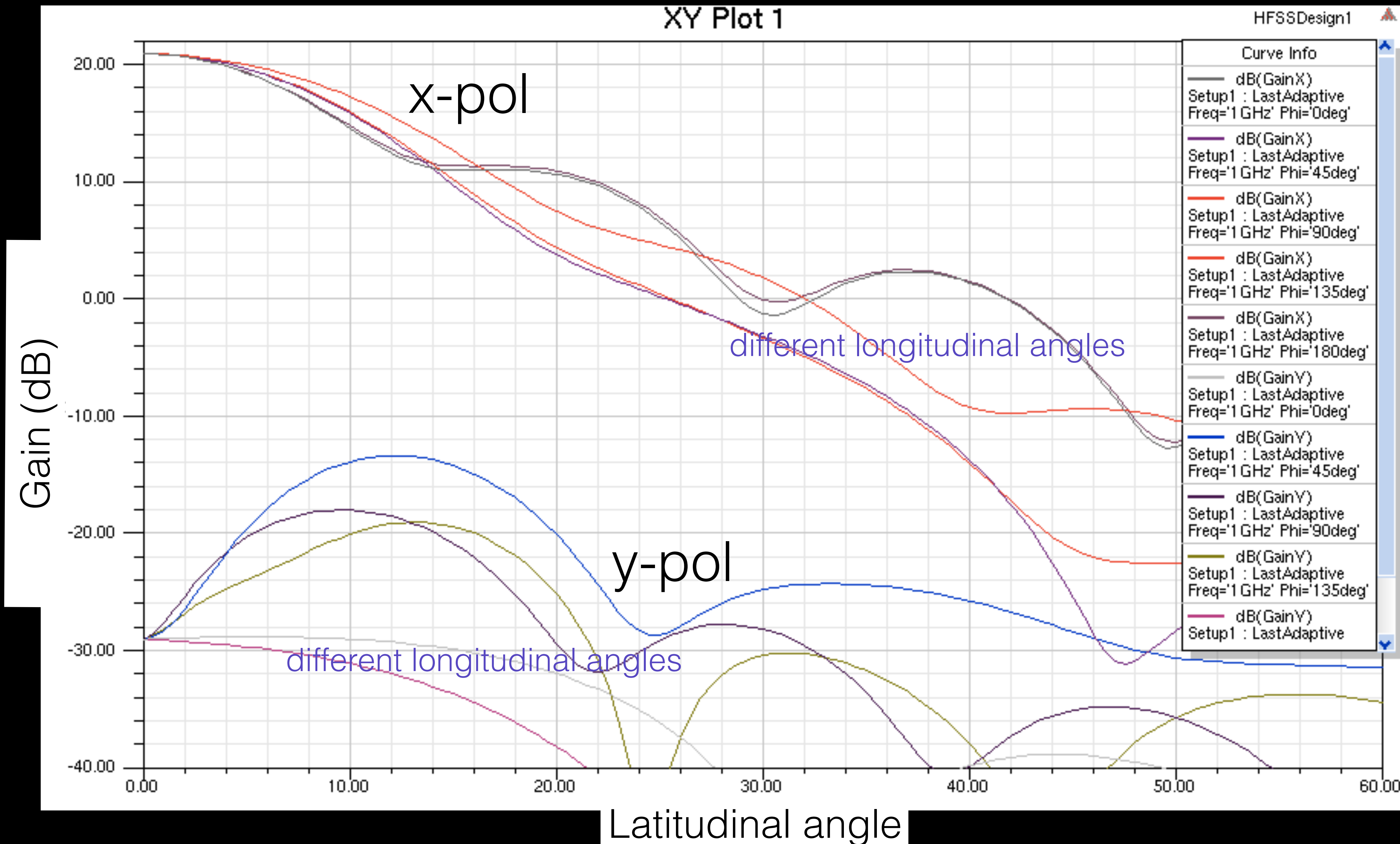
The design has a mounting surface near the transition aperture, so we just need to design a frame to support the horn. This will be a simple, four sided pyramidal horn with 46.5” diameter and 30 deg opening angle.

Pyramidal horn



Pyramidal horn

Far field beam at 1 GHz coupled to x coax



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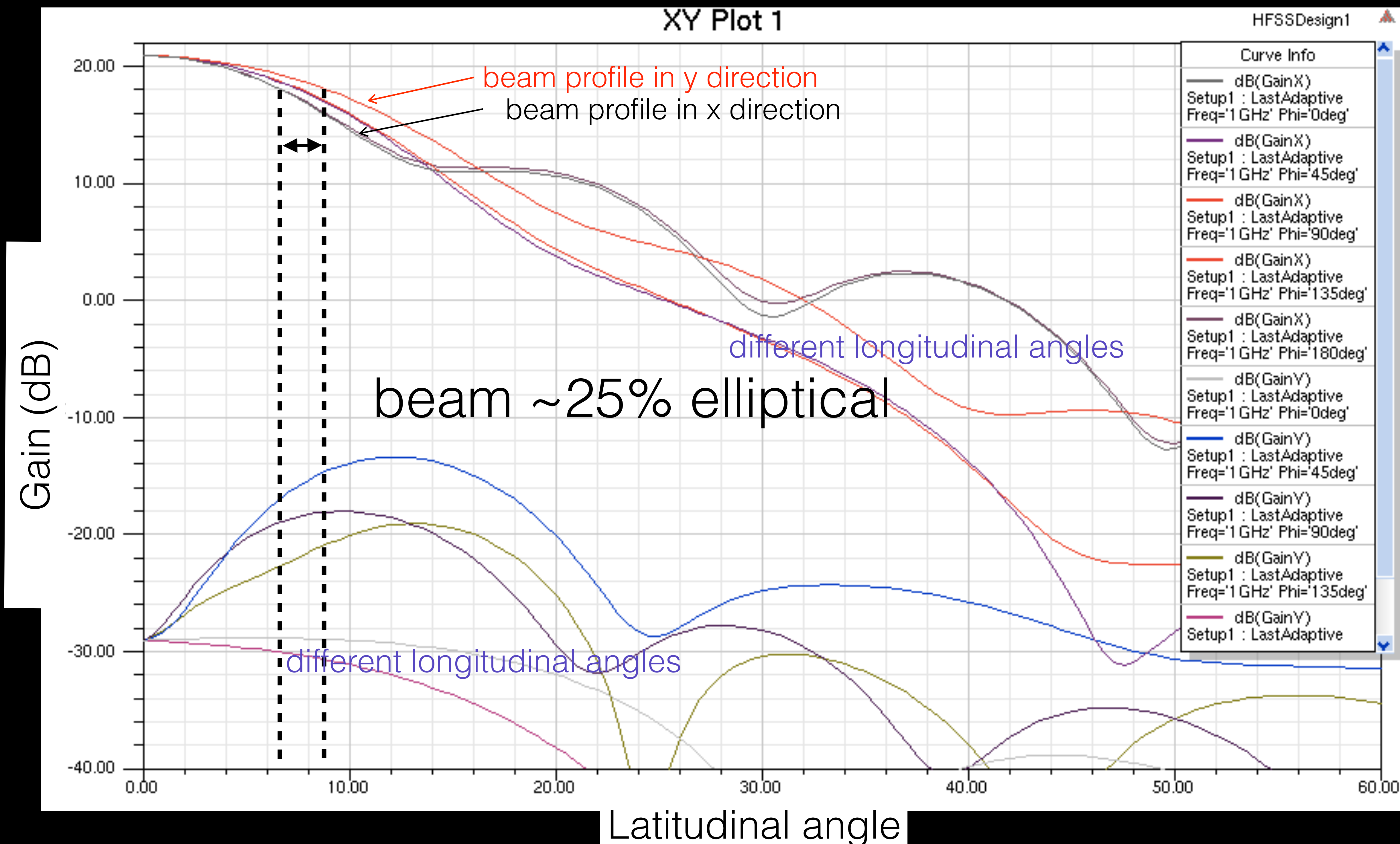

Pyramidal horn

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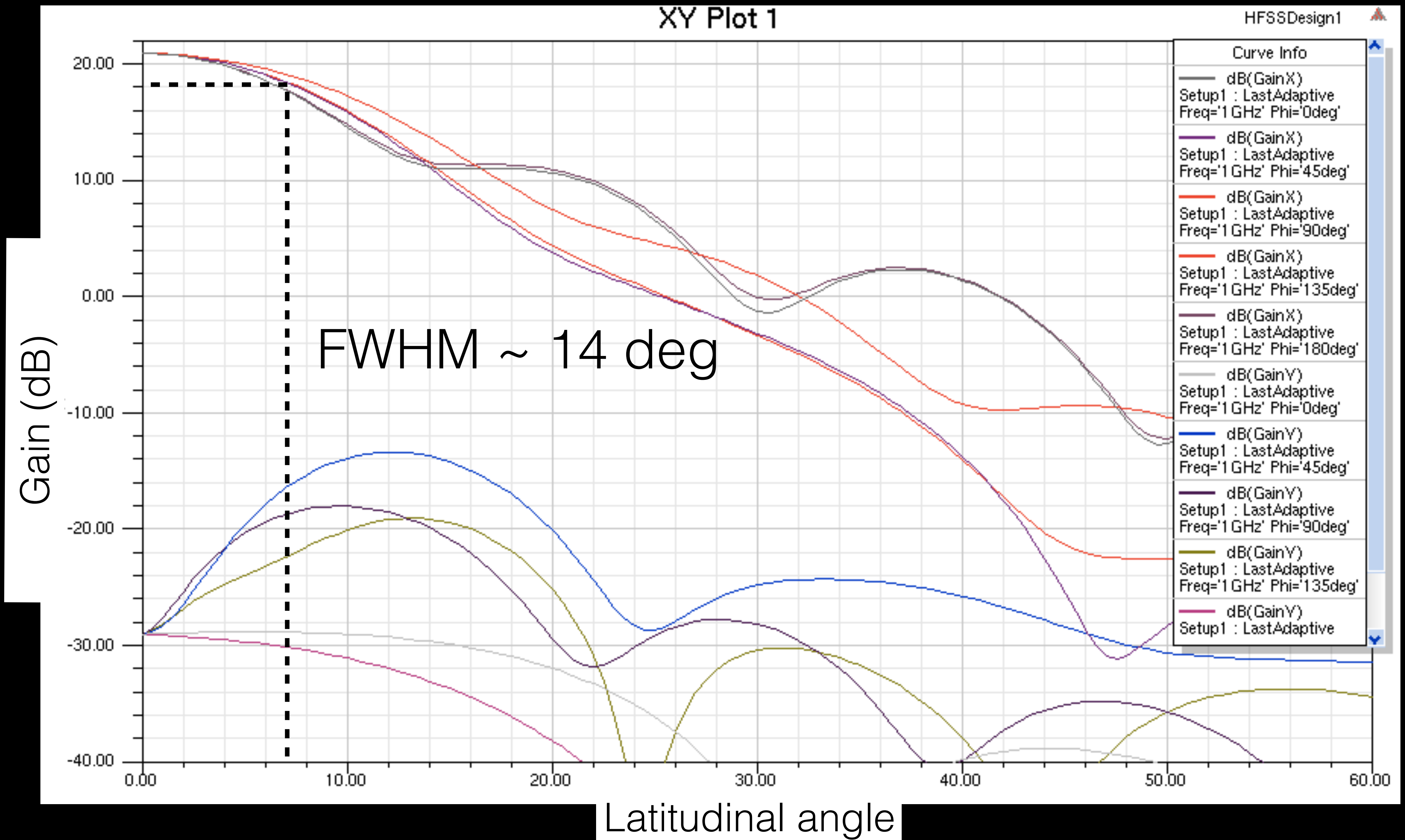
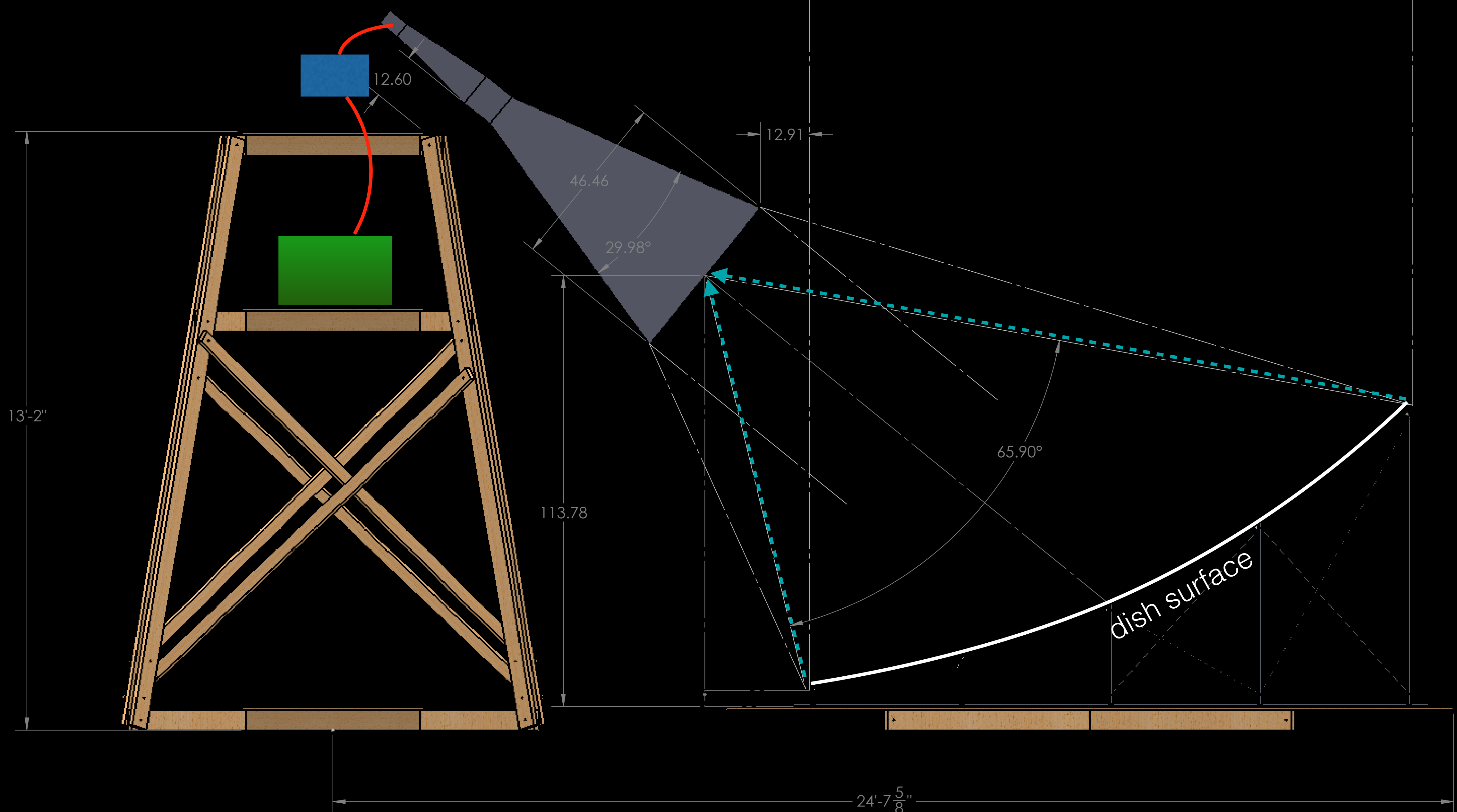
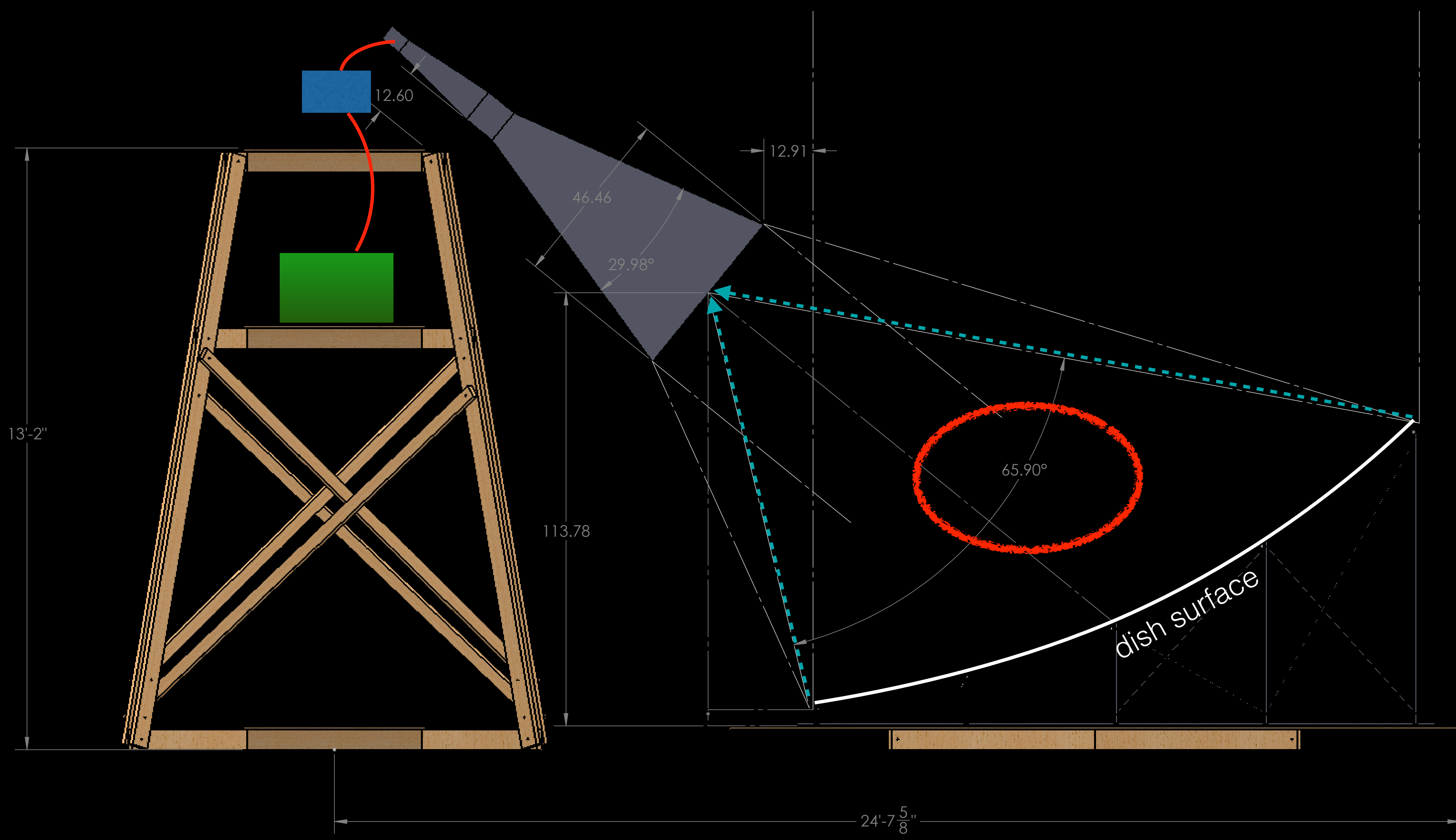


Pyramidal horn

Wanted FWHM to be 1/3 the angle the dish subtended as viewed from center of horn at 700 MHz.

14 deg * (1 GHz / 0.7 GHz) * 3 = 60 deg


12.60
12.91
46.46
29.98°
13'-2"
113.78
65.90°
dish surface
24'-7 5/8"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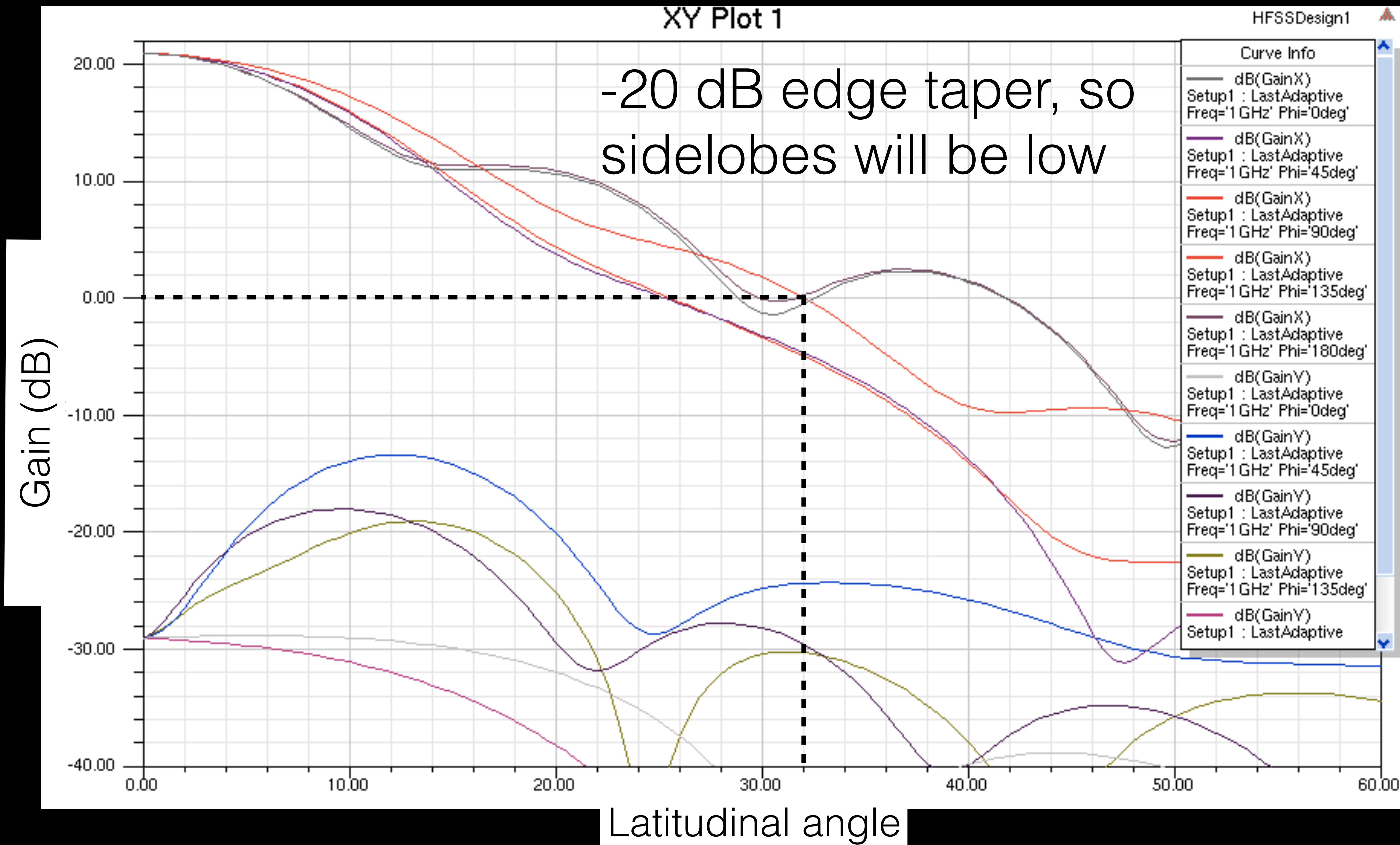

Summary

- Have designed an OMT + transition based on a VLA design
- Simulations with HFSS of a previous design match measured S_{21}; loss was not measured, need better VNA cal
- New design has >95% throughput and < 0.05 dB loss over the range 0.7 - 1.47 GHz. (The loss will almost surely be greater than predicted.)
- Drawings are nearly complete, will hand over to Jeff in next couple days.
- Coupled to a 46.5” aperture pyramidal horn, beam at 1 GHz has FWHM ~14 deg and ~25% ellipticity
- Need to design support structure for horn to bolt to transition mounting surface